Plan for Prevention of Contaminant Dispersion

Draft 1.0

EG&G ROCKY FLATS

ENVIRONMENTAL RESTORATION PROGRAM

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U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant
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EXECUTIVE SUMMARY

The Plan for Prevention of Contaminant Dispersion (PPCD) is intended for submittal to and approval by the EPA and the Colorado Department of Health (CDH) as mandated by the Interagency Agreement (IAG) between DOE and these agencies. The plan was prepared in accordance with the requirements for the PPCD specified in the IAG, EPA and DOE guidance documents, and the results of technical research and studies as reported in the professional literature.

A primary objective of the plan is to provide procedures and general models to allow DOE the capability of evaluating compliance to National Emissions Standards for Hazardous Air Pollutants (40 CFR 61 - NESHAPS), which is the most restrictive, applicable standard governing the control, assessment, and mitigation of windblown contamination.

The plan was written to provide input and general guidance to RFP remedial action plans so as to identify which actions are most likely to contribute to increased windblown contamination, identify areas where windblown contamination is most likely to occur, suggest methodology for estimating these expected emissions, propose methods and procedures to mitigate these emissions, and suggest the means to evaluate and model the airborne emissions that may result from environmental restoration activities.

The plan presents a site-wide approach applicable to each of the 178 Individual Hazardous Substance Sites (IHSS) or any of the 16 Operable Units (OUs). Each specific remedial action or set of actions will require site- specific evaluations regarding the potential for airborne emissions, determination of the quality and quantity of windblown contamination, and the evaluation and application of suitable mitigation methodologies for each situation.

The PPCD addresses the following two major topics in accordance with the IAG:

1. Part I of the PPCD provides detailed procedures for the management of wastes associated with sites at RFP so as to minimize the windblown dispersion of hazardous or radioactive materials. Procedures include soil cover over hazardous and radioactive materials and use of appropriate wetting techniques during high wind conditions. The procedures presented in the plan are intended to be used to minimize the potential for windblown dispersion of dusts containing hazardous, radioactive, or other harmful materials from all Rocky Flats Plant (RFP) sites.

2. Part II of the PPCD consists of a proposal (in two sections) to evaluate the potential for and risk of windblown inorganic, radioactive, and organic hazardous constituents released from sites at the RFP. The proposal includes details of a suitable methodology to perform screening-level assessments of risk associated with contaminated sites during all phases of the mitigation process. Information developed from these evaluations can be used to determine levels of potential airborne contamination which may be expected from remedial activities at RFP sites, so that the procedures presented in Part I may be invoked.

PREFACE

P-1 Introduction

The Rocky Flats Plant (RFP) is a federally owned nuclear weapons research, development, and production complex situated on 6,550 acres of federal property 16 miles northwest of downtown Denver, Colorado. The plant is managed and operated by EG&G Rocky Flats, Inc. (EG&G), a contractor to the U.S. Department of Energy (DOE).

The Draft Interagency Agreement (IAG), dated December 1989, between the Colorado Department of Health (CDH), the U.S. Environmental Protection Agency (EPA), and the U.S. Department of Energy (DOE), focuses on identification, characterization, and cleanup of hazardous, mixed and radioactive wastes. There are 178 identified Independent Hazardous Substance Sites (IHSS) located within and adjacent to the plant boundaries. The 178 sites are grouped into 16 operable units (OUs) based on cleanup priorities, waste type and geographic location.

The Draft IAG describes the general response process under the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), for sites containing hazardous substances at the RFP. As required by the Draft IAG, a Plan for the Prevention of Contaminant Dispersion (PPCD) shall be prepared and submitted to the EPA and the CDH for joint approval, prior to the start-up of environmental restoration activities.

P-2 SCOPE AND AUTHORITY

The DOE has developed the PPCD in accordance with the IAG among DOE, EPA, and CDH. The plan will be submitted for approval to the EPA and the CDH. These agencies share authority at the RFP for oversight of the remedial actions being conducted by the DOE. The DOE specifies that its primary operating contractor, EG&G, and any and all subcontractors performing activities shall execute this plan for all activities during remedial action phases of environmental restoration (ER) at the RFP.

P-3 POLICY

DOE's policy will be to minimize the emissions from windblown contamination that could arise during activities related to the remedial investigation and remedial action phases of environmental restoration at the RFP. Prior to the beginning of any work effort at any site designated for remedial action or investigation, an independent review of the intended action/workplan will be performed as described in this plan, in order to keep contaminated dust concentrations to levels As Low As Reasonably Achievable (ALARA).

In no event will unmitigated planned work activities be permitted which might be expected to generate concentrations of contaminants in excess of the Clean Air Act requirements at the RFP boundary or other off-site location of maximum impact. For radionuclides, the applicable limit is specified in EPA's National Emissions Standards for Hazardous Air Pollutants (NESHAPs) as 10 millirem effective dose equivalent per year. For those hazardous substances for which there is no Clean Air Act or other applicable off-site public exposure standard, the CDH and EPA will be consulted. A public exposure limit of a fraction of the TLV-TWA (see below) or Occupational Safety and Health Administration (OSHA) PEL/STEL limit will be set in accordance with CDH/EPA recommendations.

The TLV-TWA (threshold limit value, time-weighted average) is a concentration limit for worker exposure established by the American Conference of Governmental Industrial Hygienists (ACGIH). It represents a time-weighted average concentration for a normal 8-hour work day, and a 40-hour work week, to which nearly all workers may be repeatedly exposed without adverse effect. It is often used as a reference in the evaluation of impacts of ambient concentrations of toxic contaminants, although it may be modified to account for such things as full-time occupancy (rather than 40-hour exposure) and targeting less sensitive members of the population. The most recent TLV-TWA values available from ACGIH will be used when implementing this plan.

The OSHA establishes, by regulation, maximum concentrations of hazardous pollutants in air for workers, based on the recommendations of the ACGIH and others. The OSHA standards are found in 29 CFR 1910.

Instrumentation will be employed with detection limits sufficient to detect any potential hazard to human health.

P-4 PURPOSE

The procedures outlined in this plan are intended to minimize the potential for windblown dispersion of dusts containing hazardous, radioactive, or other harmful materials from all RFP sites. Part I of this plan provides procedures for the management of wastes associated with sites in such a manner as to prevent or minimize windborne transport of hazardous or dangerous materials. As further required by the IAG, Part II provides a proposal to assess the potential for and risk of windblown inorganic, radioactive and organic hazardous constituents released from RFP. The Part II proposal includes details of a suitable methodology to perform screening-level assessments of risk or impact analyses of contaminated sites during pre-mitigation, active mitigation processes, or post-mitigation. It is based on conservative principles and utilizes worst-case scenarios in order to maximize the predicted impacts. The results of the assessment will provide a basis for the evaluation of effectiveness of the clean-up technology and of proposed mitigation techniques for effectively reducing concentrations of contaminants at off-site receptors to levels which are deemed acceptable. This screening-level impact analysis should not be confused with the more detailed Baseline Risk Assessment which will be performed for each Operable Unit (OU). That assessment will make use of more detailed information on toxicity and exposure, quantify the integrated risk from all exposure pathways, consider uncertainty, and provide a risk to exposed members of the population, as well as an environmental risk. A separate plan for the evaluation of human health risk and environmental risks will be submitted in accordance with the ER IAG.

The PPCD is organized into two parts as detailed in the IAG. Part I of the PPCD provides for the management of wastes associated with sites so as to prevent windblown dispersion of hazardous or dangerous materials through techniques such as soil covering and/or use of appropriate wetting techniques during high wind conditions.

Part II of the PPCD consists of a proposal to evaluate the potential for and risk of windblown inorganic, radioactive, and organic hazardous constituents released from sites at the RFP.

P-5 DISCUSSION

As specified in the IAG, preparation of a PPCD is an integral part of site cleanup planning. The following elements were identified as steps leading to formulation of the PPCD:

1. Review and evaluation of background of material relevant to assessing the potential for and risks of windblown hazardous wastes including:

    - Summary wind rose data for conditions at the Rocky Flats Plant;
    - Aerosol resuspension studies conducted at the Rocky Flats Plant, including existing literature on soil resuspension and movement of saltating soil particles; and
    - Existing literature on respirable particle size.

2. Development of an overall evaluation of windblown contaminants from RFP, including:

    - Identification of the potential for occurrence of windblown organic, inorganic and radioactive contaminants;
    - Identification of potential risks from windblown organic, inorganic, and radioactive contamination; and
    - Identification of a high potential to contribute to windblown contamination.

3. Based on the background developed in items 1 and 2, the PPCD was prepared as specified in the IAG to include:

    - Procedures to minimize windblown contamination during high wind conditions and/or field activities, including identification of control methods;
    - A proposal to evaluate potential risks from windblown hazardous constituents; and
    - A discussion on air monitoring systems that may be useful, if required, to evaluate windblown releases from the plant.

PPCD - PART I

THE PLAN FOR MANAGEMENT OF ROCKY FLATS PLANT WASTES TO PREVENT WINDBLOWN CONTAMINATION FROM HAZARDOUS OR RADIOACTIVE MATERIALS

PART I

INTRODUCTION

Part I of the PPCD provides methods for managing RFP wastes during environmental restoration activities so as to prevent wind dispersion of hazardous or dangerous materials.

Waste disposal and various industrial operations can contaminate land surfaces with toxic chemicals and radionuclides. Soil particles from these contaminated areas can, in turn, be entrained into the air, transported off-site by the wind, and result in human exposure by direct inhalation. Indirect exposure also can result if these particulates are deposited in agricultural fields, pastures, or waterways, and thereby enter the human food chain (EPA, 1985a). Two main factors may enhance this exposure route: 1) many of the environmental compounds of concern are tightly bound to particles; and 2) conditions at many surface-contaminated sites favor wind erosion due to sparse vegetation, high wind speeds, dry soils, and high levels of activity that disturb the surface.

Contaminated soil can be reentrained to the air by three basic mechanisms:

1) Vehicle movement (rubber tired or tracked) on paved or unpaved roads;

2) Movement of soil during cleanup activities (loaders, scrapers, bulldozers); and

3) Wind erosion.

These three mechanisms can act separately or in combination. During cleanup activities all three mechanisms may be at work. Different dust suppression methods may be used to prevent wind dispersion of hazardous materials form each mechanism.

Part I of the PPCD is organized around the three major dust reentrainment mechanisms. Detailed procedures for managing RFP wastes to minimize windblown entrainment emissions from vehicle movement, soil movement, and wind erosion during environmental restoration activities are presented. The individual procedures are designed for management's use in planning the dust control measures to be applied during all phases of cleanup activities site-wide at the RFP.

PROCEDURES FOR THE PREVENTION OF WINDBLOWN CONTAMINATION:

Procedure for the Control of Windblown Contamination from Vehicle Movement

Procedure for the Control of Windblown Contamination from Soil Movement

Procedure for the Control of Windblown Contamination from Wind Erosion

PROCEDURE FOR CONTROL OF WINDBLOWN CONTAMINATION FROM VEHICLE MOVEMENT

1.0 PURPOSE

This procedure prescribes and documents the methods that will be used to control windblown contamination (dust reentrainment and airborne release of volatile organic compounds) resulting from vehicular movement during environmental restoration activities.

2.0 APPLICABILITY/SCOPE

The procedure applies to all DOE contractors, subcontractors, and their staff who engage in environmental restoration activities which could cause windblown contamination to occur during vehicle movement.

3.0 DEFINITIONS

3.1 Dust reentrainment is the process by which particulate material from soils, sediments, or dust is incorporated into the atmosphere.

3.2 Emissions (also effluents) are any treated or untreated air or liquid discharges, including stormwater runoff, at a DOE site or facility.

4.0 REFERENCES

4.1 DOE Order 5400.6, Radiological Effluent Monitoring and Environmental Surveillance, 1990.

4.2 EPA-450/3-77-010, Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions.

4.3 EPA/540/2-85/003, Handbook: Dust Control at Hazardous Waste Sites.

4.4 EPA-450/1-89-004, Vol IV, Procedures for Dispersion Modeling and Air Monitoring for Superfund Air Pathway Analysis.

4.5 EPA/540/P-87/001, Vols. I and II, A Compendium of Superfund Field Operations Methods.

4.6 DOE Order 5480.11, Radiation Protection for Occupational Workers.

4.7 Rocky Flats Plant Operational Safety Analysis (OSA) No. RFOSA-1, Contaminated Soil Removal, 6/26/89.

5.0 DISCUSSION

5.1 Dust Producing Mechanisms

Moving vehicles can entrain dust or facilitate the release of volatile compounds from soil in two ways: 1) the action of the tire grinds the road surface and forces particles backwards and up, and 2) the wind currents created by the moving vehicle cause dust from the roadway and the shoulder to be lifted up. Thus, both the road and the road shoulder must be treated. Unpaved roads must be as compacted (no loose particles) as possible to minimize the amount of loose particles) as possible to minimize the amount of loose particles to be reentrained; paved roads must be kept clear of windblown dust and spills. In both cases, the shoulders along the roadway must be as compacted as possible to make it difficult for wind currents to entrain particles.

5.2 Principles of Control

5.2.2 Unpaved Roads

Fugitive dust from unpaved roads is made up of fine soil particles coming out of the roadway, and dust suppressants act to compact these particles together to keep them from being entrained in the air. Such compaction is highly dependent on the size gradation of the aggregate materials in a roadway. A road surface will not compact unless the range of particle sizes from small to large is in the correct proportion. For example, soil that consists of predominantly silt or clay has a very poor bearing capacity, generates a large amount of dust, and becomes muddy, slippery and rutted from vehicle movement when wet. Dust suppressing agents may not penetrate, and may act to aggravate mud, ruts, and slippery conditions.

As indicated in Table 1, proper compaction and dust suppression cannot be achieved with any of the conditions listed. With too much gravel, relatively little dust will occur (until tires grind the gravel down to silt size particles), but the aggregate will be pushed to the side of the road. Any applied dust suppressant will simply pass through the top surface and provide little control.

TABLE 1

RESULTS OF IMPROPER SIZE GRADATION

Material in excess	Bearing Capacity	Amount of dust	When wet	Action of dust suppressant
Gravel	Good	Little	OK	Drains through top level of soil. Provides little control.
Sand	Poor	Some	Soft	Drains through top level of soil. Provides little control.
Silt/Clay	Very poor	Large	Mud/ruts/slippery	May not penetrate. Will aggravate mud, ruts, and slippery conditions.

EPA, 1985

With too much sand, the bearing capacity will be poor, and any dust suppressant that attempts to form a crust will not work because of rutting.

Samples of unpaved roadways must be taken to determine size gradation of soil particles. Addition of issuing aggregate sizes should be done to ensure the success of chemical dust suppressant or watering efforts.

5.2.3 Paved Roads

Reentrainment dust from paved roads is controlled by removing dirt from the road surface by sweeping, vacuuming, or flushing. Unfortunately, all these methods remove coarse particles more successfully that fine particles. Dust control for paved roads consists of moving the fine material from the roadway.

6.0 RESPONSIBILITY

6.1 It shall be the responsibility of all individuals involved in vehicle activities which could generate windblown dispersion of soil contaminants to conduct all operations in accordance with this procedure in a safe manner.

6.2 It shall be the responsibility of all project managers to ensure that copies of this procedure are available to personnel as required.

7.0 PROCEDURE

7.1 Particle Size Determination

A determination of particle size distribution of unpaved roadways will be made using five sieves (1 inch to No. 200). The percent of particles passing through each sieve will be used to determine the predominant and subdominant roadway soil types according to Table 2 (Proper Size Gradation for Unpaved Road Surface).

7.2 Correction of Roadway Aggregate Size

Table 1 (Results of Improper Size Gradation) summarizes effects of dust suppressants on roadways of differing particle sizes. If the sampling determines that the roadway aggregate does not meet the specifications on Table 2, additional aggregate of the missing sizes will be added.

7.3 Fugitive Dust Control Methods

Emissions of windblown contamination from vehicle movement will be minimized to ALARA levels. Sources of fugitive dust include unpaved and paved roads.

CAUTION: Rocky Flats Plant Operational Safety Analysis (OSA) No. RFOSA-1, Contaminated Soil Removal, mandates that all restoration operations involving soil movement shall cease and be secured whenever wind speeds exceed 15 mph.

TABLE 2
PROPER SIZE GRADATION FOR UNPAVED ROAD SURFACE

Sieve Size	% Passing	Soil Type
1 in.	100	
3/4 in.	85-100	
3/8 in.	65-100	Gravel
No. 4	55-85	
No. 10	40-70	
No. 40	25-45	Sand
No. 200	10-25	Clay, Silt

EPA, 1985

7.3.1 Unpaved Roads

The dust control efforts that will be used on unpaved roads shall consist of watering when determined necessary by the remedial project manager, speed control (i.e., 5 miles per hour for all vehicles), and good housekeeping practices. Signs will be posted in the vicinity of remedial action sites specifying adherence to the 5 mph speed limit.

7.3.1.1 Watering

When needed, water will be applied to the unpaved road surface with a water wagon or spray bar. The quantity will vary with the road surface material, sunlight, humidity, and traffic level. Effectiveness may be greater during evening hours and during periods of high humidity.

CAUTION: In no case will water be applied to unpaved roadways in a manner or quantity which could result in runoff from the roadbed sufficient to disperse particulate contaminants to surrounding areas.

Water will be applied with water wagons equipped with two to five nozzles that shoot a flat spray behind the vehicle. Where spray wagons are used, operators shall ensure that excess watering does not cause contaminant runoff from roadways to adjacent areas.

7.3.1.2 Roadway Preparation

Proper roadway preparation is essential for dust control. Preparation steps will include adding aggregate to the surface as required to obtain the size gradation listed in Table 2, and grading the road with a center crown with no low spots for water to collect. Grading may be required every 1-2 weeks with watering.

7.3.1.3 Vehicular Speed Control

Reducing vehicular speed on unpaved roadways may significantly reduce dust emissions (EPA, 1985a). A reduction in speed from 30 to 20 mph may reduce emissions by 33 percent (EPA, 1985a). Reduction in dust emissions is offset by increased labor equipment time to haul material. Site specific speed limits on unpaved areas and roadways shall be established for each environmental restoration activity, consistent with good management practices of cost versus benefit and prevailing environmental conditions.

7.3.1.4 Housekeeping Practices for Unpaved Roadways

Housekeeping refers to cleaning up spills and track-on material left by the trucks. These materials have not been wetted and can become easily reentrained. Costs include labor and equipment time to remove.

Housekeeping shall be effected by minimizing spills and carryout. Measures to minimize spills shall include the use of trucks with tailgates as opposed to scows, eliminating truck leaks, not overfilling trucks, and covering loads. Spills and track-on material shall be removed from roadways prior to resuming traffic to minimize reentrainment. Carryout will be minimized by regrading or graveling to eliminate muddy areas, and by requiring all trucks to pass through a truck tire and underbody wash when leaving O.U. areas. A high pressure hot water wash for equipment which could be contaminated will be utilized as required by Rocky Flats OSA No. RFOSA-1. Waste water from the washing operation shall be considered contaminated until determined otherwise.

7.3.2 Paved Roads

Paved roads become dirt-laden from spills, track-on, and windblown dust. The control methods used on paved roads are manual cleaning, mechanical sweeping, flushing, and general housekeeping practices. The objective of these practices is to remove all loose dirt, especially the fine particles. One or all of the following methods will be used as determined by the project manger.

7.3.2.1 Manual Cleaning

Manual cleaning is very labor intensive, but may be used for short sections of road as required.

7.3.2.2 Mechanical Sweeping

Mechanical street sweeping is the most common means of dust control; however, it is relatively ineffective in the removal of fine particles. Silt-size particles (less than 74 micrometers) are the particles most likely to be entrained. Removal efficiency of mechanical sweeping for this size particle is less than 46 percent. Mechanical street cleaning itself creates dust because of the impact of the cleaning vehicle tires on the road, the brushing of dry pavement, and wind turbulence caused by exhaust and vehicle movement. Unless the street is very dirty, the net improvement in ambient air quality as a result of sweeping will be small or negative. Mechanical sweeping will ordinarily be used only in conjunction with other methods as outlined below.

7.3.2.3 Water Flushing

Water flushing hydraulically moves particulate material to roadway margins or gutters. Flushing is frequently used in conjunction with vacuum sweeping rather than as the sole method of cleaning. Flushing before sweeping is used to wash street dirt to gutters for collection by motorized sweepers. When utilized in this manner, the flushing requires smaller quantities of water and lower nozzle pressures. The benefits of flushing after sweeping instead of before are that the entire pavement is made cleaner and only small quantities of dirt are washed into inlets and catch basins. Like sweeping, flushing is more effective in the removal of larger particles than fine particles. Water flushing will be used for dust control on paved roadways when cost effective, so long as contaminants are not spread to adjacent areas.

7.3.2.4 Housekeeping Practices for Paved Roadways

The same housekeeping practices shall be applied to paved roads as for unpaved roads (see Section 7.3.1.4), including measures to minimize material spillage and dirt track-on, and expedite cleanup when they do occur. Small hand-operated vacuum cleaners equipped with HEPA filters will be used for cleanup of small spills on roadways. If required, road cleaning and flushing may be done. In all cases, flushing will be done after vacuuming (see Section 7.3.2.3). Dry sweeping will not be performed since the sweeping action will probably generate more dust than it will pick up.

8.0 RECORDS AND REPORTS

Records or logs of dust and contamination control measures that have been enacted will be maintained. Such logs will include the date and time, the area affected, the type of control measure used, and the supervisor's initials verifying that the work was accomplished in a satisfactory manner. These records and logs will be maintained permanently as part of the documentation of the environmental restoration effort.

PROCEDURE FOR THE CONTROL OF WINDBLOWN CONTAMINATION BY SOIL MOVEMENT

1.0 PURPOSE

This procedure prescribes and documents the methods used to control windblown contamination generated by moving soils during environmental restoration activities.

2.0 APPLICABILITY/SCOPE

The procedure applies to all DOE contractors, subcontractors, and their staff who may be involved in earth moving which could generate airborne emissions from dust, soil particles, or volatile organic substances during environmental restoration activities. Such emissions could be generated from soil movement by dozers, front-end loaders, material dumping or loading into trucks or storage boxes, drilling, and/or other grading and construction activities. The procedure is directed primarily to activities performed in areas containing potentially hazardous soil contaminants.

3.0 DEFINITIONS

3.1 Emissions and effluents are any treated or untreated air or liquid discharges, including storm water runoff, at a DOE site or facility.

3.2 Soil drop refers to the manual or mechanical transfer or dumping of soils.

3.3 Dust reentrainment is the process by which particulate material from soils, sediments, or dust is incorporated into the atmosphere.

4.0 REFERENCES

4.1 DOE Order 5400.6, Radiological Effluent Monitoring and Environmental Surveillance, 1990.

4.2 EPA-450/3-77-010, Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions.

4.3 EPA/540/2-85/003, Handbook: Dust Control at Hazardous Waste Sites.

4.4 EPA-450/1-89-004, Vol. IV, Procedures for Dispersion Modeling and Air Monitoring for Superfund Air Pathway Analysis.

4.5 EPA/540/P-87/001, Vols. I and II, A Compendium of Superfund Field Operations Methods.

4.6 DOE Order 5480.11, Radiation Protection for Occupational Workers.

4.7 Rocky Flats Plant Operational Safety Analysis (OSA) No. RFOSA-1, Contaminated Soil Removal, 6/26/89.

4.8 Rocky Flats Plant Operational Safety Analysis (OSA) No. 250.002, Remedial Investigation Drilling and Sampling Program, 1/5/90.

5.0 DISCUSSION

Movement of dirt that could contain hazardous contaminants may result from bulldozers moving soil, front-end loaders loading soil into trucks for on- or off-site removal, drilling activities, and manual operations. Control of emissions from vehicular movement is discussed in a separate procedure. This procedure addresses means of minimizing emissions from dozers, front-end loaders, material dumping into trucks and storage boxes, drilling, and construction activities conducted in areas containing potentially hazardous soil contaminants.

5.1 Bulldozers and Scrapers

The tracks and blade of a bulldozer are the sources of emissions. Bulldozer tracks reentrain dirt in much the same manner as vehicle wheels, except the grinding action is somewhat greater. The top and sides of the blade generate emissions as dirt slides off. This is particularly true of the top of the blade, where thin layers of dirt can easily be carried off by the wind.

5.2 Front-end Loaders

Emissions from front-end loaders emanate from the tracks or wheels as well as the loader bucket. The usual source of emissions from the loader bucket results from soil drop and spillage as the bucket is being raised (see Section 5.3).

5.3 Soil Drop

The soil drop creates two sources of dust: 1) when the wind picks up soil particles from the edges of a mass of dirt as it is being dropped; and 2) air turbulence causes dust reentrainment as the mass of dirt is dropped into the truck or storage box. In the latter case, the displacement of air out of the tuck or box caused by the mass of dirt moving downward causes soil already in the truck to rise along with soil from the edge of the dirt mass being dropped.

5.4 Drilling

Drilling activities may give rise to airborne emissions from two basic sources: dispersion of contaminant material from drill cuttings; and dispersion of dried drilling mud or other fluids.

6.0 RESPONSIBILITY

6.1 It will be the responsibility of all individuals involved in soil moving activities which could generate windblown dispersion of soil contaminants to conduct all operations in accordance with this and other approved procedures, and in a safe manner.

6.2 It will be the responsibility of all project managers to ensure that copies of this procedure are available to personnel as required.

7.0 PROCEDURE

Methods of control of windblown contamination resulting from the above activities will be controlled through water spraying as specified below.

7.1 Vehicle Movement

Method for controlling windblown contamination from vehicle movement of dozer, scrapers, and front-end loaders shall be accomplished in accordance with a separate "Procedure for the Control of Windblown Contamination from Vehicle Movement."

7.2 Bulldozers, Scrapers, and Front-end Loaders

As soil is moved by dozers, scrapers, and front-end loaders, new soil is continuously exposed. Therefore, dust control measures must also be continuous or occur at frequent intervals. Water spraying of areas being worked will be done at frequent intervals to minimize windblown contamination to adjacent areas. Wetting will be done using water spray wagons or water sprayers as needed. Surface spraying will also minimize emissions from vehicle tracks or wheels and from soil dropped from scoops and buckets.

7.3 Soil Drop

Although area spraying effects some reduction in emissions resulting from material drop, the spray does not treat the bulk of the material being dropped, and significant emissions are still present. Basic control methods will include inducing moisture into the drop cycle, using windscreens to decrease wind speed around the drop receptacle, and reducing the number of soil drops by direct loading into storage containers whenever possible.

CAUTION: Rocky Flats Plant Operational Safety Analysis (OSA) No. RFOSA-1, Contaminated Soil Removal, mandates that all operations shall cease and be secured whenever wind speeds exceed 15 mph.

7.3.1 Soil Watering

For soils containing high levels of radioactive particle contaminants, a mobile frame fitted with a series of spray nozzles may be positioned in the field so that trucks can drive under the frame. The flat spray from the nozzles will be adjusted to form a "spray curtain" across the entire horizontal surface of the truck box. The spray will only be operated during the actual dump, and water will be used. The system will not be operated continuously, but will be turned on by the truck driver or operated remotely by the front-end loader operator.

7.3.2 Wind Screens

Screening dozer and loading operations from wind can be a useful and cost effective means of minimizing windblown particulate and vapor contaminant dispersion. Portable windscreens can be positioned to shield only the dump cycle or to shield both the dump cycle and the front-end loader operation. The screen height should exceed the height of the front-end loader bucket drop by at least one foot, and should be two screen heights wider than the width of the area being worked. Screen porosity should be 50 percent. The screen effectively shelters a downwind distance of about 7 to 10 screen heights and reduces windspeed by as much as 50 percent at the surface. Emissions from operating bulldozers or front-end loaders are not reduced, but the lower windspeed causes the dust to drop to the ground quicker. The same is true of the material drop cycle. The plume from the material drop shall be prevented from going over the height of the screen, since no control is provided for that part of the plume, and wind eddies from the windscreen may carry the dust even farther.

7.3.3 Application Methods for Watering

A spray curtain will be purchased from a commercial vendor or fabricated locally if cost effective. For best results, it must be mobile so that it can be moved close to the excavation point to minimize front-end loader travel. The system can be mounted on a large frame under which a truck can drive, and it should surround each side of the truck box. Each side of the frame should contain two to eight nozzles, depending on the length of the truck to be loaded and the spray width of the nozzles. The masts on which the nozzles are mounted should be adjustable in height so that they can accommodate different truck heights and different site grades. It is essential that the flat spray be directed over the top of the truck box. The system shall only be turned on during actual dumping to avoid excessive liquid, and the nozzles shall be set for a flat spray instead of a mist, as a mist will not form a total spray curtain during windy conditions.

7.4 Drilling

Potentially contaminated material from drill cuttings and drilling mud shall be controlled in accordance with Rocky Flats Operational Safety Analysis Contaminated Soil Removal, No. RFOSA-1 and other applicable procedures.

7.4.1 Drill Cuttings

The material collected shall be considered and treated as hazardous and/or radioactive waste until determined otherwise. In no instance will such material be allowed to remain exposed to weathering to become a potential source for airborne particulate contamination.

7.4.2 Drilling Mud and/or Fluids

Drilling mud or fluids shall be considered and managed as hazardous and/or radioactive waste until determined otherwise. Drilling fluids will be collected in decontamination troughs or mud pits. The liquid in these troughs will be decanted into a tanker truck. Care must be taken in preventing sediments from entering the tanker. The remaining solids from the troughs will be solidified per Contaminated Soil Removal, No. RFOSA-1.

8.0 RECORDS AND REPORTS

Records or logs of dust and contamination control measures that have been accomplished in the field shall be maintained. Such logs will include the date and time, the area affected, the type of control measure used and the supervisor's initials verifying that the work was accomplished in a satisfactory manner. These records and logs shall be maintained permanently as part of the documentation of the environmental restoration effort.

PROCEDURE FOR THE CONTROL OF WINDBLOWN CONTAMINATION FROM WIND EROSION

1.0 PURPOSE

The purpose of this procedure is to prescribe and document the methods that will be used to control windblown contamination (dust reentrainment and airborne release of volatile compounds) resulting from wind erosion of exposed soil surfaces during environmental restoration activities.

2.0 APPLICABILITY/SCOPE

The procedure applies to all DOE contractors, subcontractors, and their staff who engage in environmental restoration activities which could cause windblown contamination from soil erosion to occur during the course of such activities.

3.0 DEFINITIONS

3.1 Dust reentrainment is the process by which particulate material from soils, sediments, or dust, is incorporated into the atmosphere.

3.2 Emissions (and effluents) are any treated or untreated air or liquid discharges, including stormwater runoff, at a DOE site or facility.

3.3 Saltation refers to hopping or bouncing movement of a particle of 80 to 1000 micrometer diameter.

3.4 Surface creep refers to rolling and sliding movements of particles of generally greater than 1000 micrometer diameter.

4.0 REFERENCES

4.1 DOE Order 5400.6, Radiological Effluent Monitoring and Environmental Surveillance, 1990.

4.2 EPA-450/3/-77-010, Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions.

4.3 EPA-450/3-74-036a, Investigations of Fugitive Dust, Vol. I, Sources, Emissions, and Control.

4.4 EPA/540/2-85/003, Handbook: Dust Control at Hazardous Waste Sites.

4.5 EPA-600/8-85/008, EPA Guide for Minimizing the Adverse Environmental Effects of Cleanup of Uncontrolled Hazardous Waste Sites.

4.6 EPA-450/1-89-004, Vol. IV, Procedures for Dispersion Modeling and Air Monitoring for Superfund Air Pathway Analysis.

4.7 Rocky Flats Plant Occupational Safety Analysis (OSA) No. RFOSA-1 (6/26/89), Contaminated Soil Removal.

4.8 EPA/540/A-87/001 Vols. I & II, A Compendium of Superfund Field Operations Methods.

4.9 Rocky Flats Plant, Procedure for Contaminated Soil Removal, No. WO-5100.

5.0 DISCUSSION

5.1 Dust Producing Mechanisms

Wind erosion of exposed soil areas or piles occurs from soil transported by surface creep, saltation, or suspension, depending on the particle diameter.

Wind erosion is usually an intermittent activity that occurs above a threshold wind velocity. Estimates of this threshold velocity vary from about 10 to 20 mph across different soil types, aggregates, and meteorological conditions. Wind erosion emissions vary with soil particle size, moisture, and windspeed.

5.2 Principles of Control

5.2.1 Reduction of Windspeed

The following methods can reduce windspeed at the soil surface:

1) Covering the pile with a wind-impervious fabric or vinyl.
2) Erecting a windscreen.
3) Pile orientation and pile shape.
4) Establishing a covering of vegetation using hydro-mulching.

5.2.2 Development of Less Erosion-Prone Soil Surfaces

Methods of forming new, less-erodible surfaces are:

1) Water spraying to compact and weight soil particles.

2) Establishment of vegetation. The roots bind the soil together, and the stems reduce windspeed at the surface.

3) Use of "clean" soil covers, including mulches. Paving can be used for long-term erosion control.

5.3 Erosion Control Methods

The products below will be used as required, depending on the site specific conditions at IHSS. These methods may be used in combination during different phases of the remedial action. Products for dust control of exposed areas and undisturbed storage piles include:

1) Covers, liners, and geotextiles that are impermeable to the wind. Some are also impermeable to liquids.

2) Windscreens that decrease windspeed on the downwind side.

3) Spray systems that spray water every few hours to cover or moisten the soil.

4) Application of binders with grass seed (i.e., hydro-mulching) to form a soil admixture.

5.3.1 Covers, Liners and Geotextiles

Liners will not allow water or many chemicals to pass. Geotextiles will allow liquids to pass but may not be tolerant of certain chemicals. Because geotextiles are more commonly used for prevention of soil erosion, information results of chemical compatibility testing are not available. Some liners and geotextiles may also suffer from ultraviolet degradation when exposed to sunlight.

Installation of a liner or fabric first requires careful site grading to eliminate rocks, large dirt clods, or sharp objects that might puncture the material. The site must also be graded so there are no low spots to collect liquid. This is particularly important with fabrics.

Liners and fabrics typically come in rolls of 12 feet or greater width. Seams are either overlapped, sewn, pinned, solvent or heat welded, or attached with an adhesive. The edges are typically anchored in a trench filled with soil.

5.3.2 Windscreens

Specifications of the screen size and spacing between the screen and the dust source are very important. Product vendors can assist in determining specifications. Most important of these are:

1) Screen Height: Height must be 2 to 4 feet above the source height. Too low a windscreen will actually increase downwind emissions because of wind shear.

2) Distance From Screen to Pile: The downwind extent of sheltering is reported in terms of number of equivalent screen heights. The distance at which maximum windspeed reductions occur is 3 to 5 screen heights downwind.

3) Screen Length: With winds exactly perpendicular to a screen, the sheltered area will extend almost straight downwind from the two ends of the screen for a distance of 10 to 15 screen heights. The screen must be extended beyond the edges of the area to be protected to compensate for changes in wind direction that occur

over time. It is recommended that the screen extend beyond the area to be protected by 10 screen heights for a large field (greater than 10 screen heights in width) or one source width for a small source (less than 10 screen heights in width) such as temporary storage pile.

4) Screen Porosity: Air that passes through the windscreen fabric is referred to as "bleed flow"; air that is displaced upward over the screen is called "displacement flow." A more porous or permeable screen has higher bleed flow and less shear in the flow at the screen top. The higher porosity results in less reduction in mean windspeed immediately downwind of the screen, but a slower recovery to the upwind condition farther downwind of the screen. Above the porosity of 40 to 50 percent, large-scale eddying at the displacement flow and a zone of stagnant flow is no longer apparent. A 50 percent porosity screen provides an optimum mix of wind velocity reduction, depth of shelter area, and low turbulence.

5) Terrain Roughness: The smoother the terrain on which a windscreen is erected, the greater the reduction in windspeed downwind of the screen. Also, the zone of reduced windspeed becomes larger as upstream terrain roughness and air turbulence are decreased.

5.3.3 "Clean" Covers and Mulches

Storage piles containing hazardous materials can be temporarily covered with clean soil or gravel prior to cleanup. However, this method results in a larger volume of hazardous waste material requiring disposal. For larger areas, commercial mulches are available, some of which can be impregnated with grass seed. These products contain a binder to hold the soil while the grass grows. Similar products are available that are routinely used to vegetate highway excavations after construction. Before application of these latter produces, the site must be well graded and well drained.

6.0 RESPONSIBILITY

6.1 It will be the responsibility of all individuals involved in vehicle activities which could generate windblown dispersion of soil contaminants to conduct all operations in accordance with this procedure in a safe manner.

6.2 It will be the responsibility of all project managers to ensure that copies of this procedure are available to personnel as required.

7.0 PROCEDURE

Emissions of windblown contamination from soil erosion will be minimized to levels As Low As Reasonably Achievable (ALARA).

7.1 Windblown Contamination Control Methods

7.1.1 Exposed Areas

The contamination control methods that will be used on exposed areas to prevent soil erosion include long-term (months/years) and short-term (weeks) alternatives.

7.1.1.1 Long-term control methods will be used whenever cleanup for exposed areas will take more than three months to accomplish. Control methods will include covering with soil covers or synthetic membranes as required.

7.1.1.2 Short-term or temporary control methods will be used whenever it is anticipated that cleanup of exposed areas can be accomplished in less than three months. Short-term or temporary control methods will include watering or covering as deemed appropriate.

7.1.2 Storage Piles

Windblown contamination control methods for storage piles will include techniques for inactive and active storage piles.

7.1.2.1 Inactive Storage Piles

Soil erosion from inactive storage piles will be controlled by covering, watering, using wind screens, soil mulching, and pile orientation as deemed appropriate.

7.1.2.2 Active Storage Piles

Contamination control methods that will be used to prevent soil erosion from active storage piles will include covering the unused sections of the pile, watering, pile orientation, and wind screens, as deemed appropriate.

7.2 Application of Control Methods

7.2.1 <u>Watering</u>

When needed, water will be applied to the exposed areas or storage piles with a water wagon. The quantity will vary with the surface material, sunlight, humidity, and wind speed. Effectiveness may be greater during evening hours and during periods of high humidity.

CAUTION: In no case shall water be applied to unpaved areas in a manner or quantity which could result in runoff sufficient to disperse particulate contaminants to surrounding areas.

7.2.1.1 Spray Wagons

Water will be applied with water wagons equipped with two to five nozzles that shoot a flat spray behind the vehicle. Where spray wagons are used, operators shall ensure that excess watering does not cause contaminant runoff from roadways to adjacent areas.

7.3 Installation of Covers, Liners, and Geotextiles

7.3.1 Preliminary Site Grading

Installation of a liner or fabric will first require careful site grading to eliminate rocks, large dirt clods, or sharp objects that might puncture the material. The site will also be graded so there are no low spots to collect liquid. Control of airborne materials during these operations is governed by a separate procedure for the Control of Windblown Contamination from Soil Movement.

7.3.2 Installation

Liners and fabrics typically come in rolls of 12 feet or greater width. Seams will be either overlapped, sewn, pinned, or attached with an adhesive. The edges will be placed in a excavated shallow ditch and covered with clean soil.

CAUTION: Rough handling or poor preliminary site grading can result in tears in covers and fabrics, which will significantly reduce their lifetime and effectiveness and should be avoided.

7.4 Installation of Windscreens

Windscreens may be mounted either permanently or temporarily. When mounted permanently, they will be mounted on poles, the spacing of which will depend on windscreen height and pole material, according to vendor recommendations. Windscreens come in 3- or 4-ft widths, and heights must be multiples of these widths. Windscreens are also available in 10-ft by 10-ft panels mounted within an aluminum frame. These frames can be moved by two persons. Other applications may consist of attaching the screen to poles set in cement blocks, which may be moved by a forklift as a semipermanent installation.

8.0 RECORDS AND REPORTS

Records or logs of dust and contamination control measures that have been accomplished shall be maintained. Such logs will include the date and time, the area affected, the type of control measure used, and the supervisor's initials verifying that the work was accomplished in a satisfactory manner. These records and logs will be maintained permanently as part of the documentation of the environmental restoration effort.

PART II

PROPOSAL TO EVALUTE THE POTENTIAL FOR AND RISK OF WINDBLOWN INORGANIC, RADIOACTIVE, AND ORGANIC HAZARDOUS CONSTITUENTS

INTRODUCTION

Part II of the PPCD proposes the methods for evaluating the potential for and risk of windblown inorganic, radioactive and organic hazardous constituents released from sites at the RFP.

EPA guidance specifies that before implementing remedial activities, the potential impacts resulting from release to the atmosphere of noxious or hazardous materials be evaluated using established procedures. Gases, aerosols, or particles may be emitted as a result of routine operations or because of an accident (fire, explosion, etc.). The subsequent transport and diffusion of these materials could result in downwind concentrations, either on-site or off-site, that could adversely affect environmental quality or public welfare. After evaluating the potential sources of such emissions and their likelihood of occurrence, air-quality dispersion modeling techniques can be used to estimate the locations and magnitude of maximum impacts (Turner 1967; Hanna et al. 1982; Ramsdell and Athey 1981). Meteorological data for these studies may be provided through an on-site monitoring program or from historical observations collected at nearby weather stations. The results of these evaluations can be used to estimate maximum impacts and provide guidelines for construction-related activities to help minimize emissions, particularly during periods of unfavorable atmospheric conditions (EPA Rosbury, 1985).

Part II has been developed in two major sections: the proposed methods to identify sites with the potential for windblown contaminants; the proposed methods to identify the risks of off-site migration of those contaminants; and the proposed methods for preparing dispersion models and airborne pathway analysis.

In each case, the proposals outline the methods to be used in a step-by-step manner, and include detailed discussions of applicable analytical methods after the presentation of the main outline.

SECTION 1

PROPOSAL TO IDENTIFY AND EVALUTE AREAS OR SITES WHICH HAVE THE POTENTIAL FOR WINDBLOWN ORGANIC, INORGANIC AND/OR RADIOACTIVE CONTAMINANTS

INTRODUCTION

Release mechanisms for particulate contaminants include wind erosion and mechanical disturbance, vehicular traffic, soil removal and other activities associated with site clean-up. Release mechanisms for volatile contaminants include spills and leaks of volatile material, and release of volatiles to the atmosphere from contaminated soils, impoundments, and contaminated run-off.

Proposed contaminant release screening principles will require a determination of the likelihood of release from each source, the nature of the contaminants involved, and the probability magnitude of their release relative to other sites (EPA 1988). The means of identifying areas or sites within Rocky Flats which have the potential for windblown organic, inorganic and/or radioactive contaminants are proposed as follows:

1.0 LIKELIHOOD OF WINDBLOWN EMISSIONS

It is proposed that determination of the likelihood of releases to the atmosphere will be based on an evaluation of the following factors:

1.1 Storage Mechanism Integrity

Integrity of storage mechanisms at the RFP will be evaluated to address the following concerns:

1.1.1 Volatilization occurs most often at landfill sites where the soil cover is not impervious to rainfall or run-on. In such cases, wastes can be leached, and migration of volatile contaminants can occur. Factors such as extreme drying and erosion can reduce the ability of soil to maintain the isolation of wastes. It is proposed that current conditions and the long-term integrity of the cover be evaluated.

1.1.2 Above ground storage of containers may allow airborne contaminant release from corrosion and leakage of containers.

1.1.3 Volatilization occurs at open impoundments where volatile compounds may be released to the atmosphere.

1.2 Volatilization from Contaminated Soils, Impoundments, or Permeation Through Covers

The potential for volatilization from contaminated soils or impoundments will be evaluated based on factors including soil porosity, phase transfer coefficient, liquid-phase transfer concentration of the contaminant in the soil, soil moisture, and temperature.

The effectiveness of various landfill cover types and depths will be evaluated based on soil porosity, exposed area, the diffusion coefficient of the component, saturation vapor concentration of the potentially released component, and mole fraction of the component.

1.3 Potential for Wind Erosion

Particulate contaminants are more likely to become airborne at those sites where the contaminants are located in uppermost soil layers and are subject to wind erosion and other mechanical forces such as worker vehicle traffic. Areas with soil which is fully exposed to the forces of the prevailing flow (i.e., not sheltered by nearby structures), where the soil is dry, erodible, non-vegetated or not otherwise covered, or soil disturbed by cleanup or construction activities may also lead to airborne contamination.

Precipitation patterns will impact the soil moisture levels (as discussed later in the equation for wind erosion analysis), affect the rate of volatilization from contaminated soils or covered landfills (as will be discussed later in the equation to estimate volatiles released from covered landfills), and provide a mechanism for the corrosion of containers. The severe terrain to the west of the Rocky Flats site may also serve to channel and accelerate prevailing westerly winds.

Due to the unique factors at the RFP, a literature search to investigate and identify applicable techniques for the prediction of wind erosion and windblown contamination from exposed areas was conducted. The material surveyed included EPA guidance documents, RI/FS studies conducted for other sites, previous investigations specific to the Rocky Flats site, and the scientific literature. A summary of the review and its findings follows below with the proposed selection of two independent methods.

1.3.1 Modes of Soil Erosion

The majority of the historical research investigating windblown dust was oriented toward the study of soil wind erosion losses from agricultural fields (for example, Chepil 1945a; 1945b). During the course of these experiments several modes of soil erosion or particle movement were investigated. Particles were found to become airborne by the drag of wind against the soil or by being knocked loose by existing airborne particles.

The three primary modes of particle movement are surface creep, saltation, and suspension. Surface creep typically involves the largest particles (>1000 μm) and only results in movement of several meters by rolling or sliding along the surface. Saltation usually affects the middle size range of particles (550 - 1000 μm) and refers to short particle trajectories near the surface. Particles moving by saltation usually migrate only short distances during an eroding event, but are responsible for the production of fine particulate through a "sandblasting" effect (Gillette, et al., 1974). Suspended particles can be transported over great distances depending on their size. Suspended particles from agricultural fields were observed to be generally less than 50 μm (Chepil 1957). Most eroding soil moved only short distances by saltation or surface creep unless the terrain was virtually free of features that obstructed or trapped particles or where the wind velocity exceeded the erosion threshold for long periods of time (Gillette 1976).

1.3.2 Wind Erosion Equation

Research on agricultural fields resulted in the development of a Wind Erosion Equation (sometimes referred to as the Universal Soil Loss Equation). Woodruff and Siddoway (1965) simplified the complex relationships between the variables and presented an equivalent technique based on five parameters: soil erodibility index, soil ridge roughness factor, climatic factor, field length along the prevailing fetch, and a vegetation cover factor. Some relationships originally developed in terms of measured soil parameters were replaced by procedures normalized to well-studied sites and expressed in terms of an annual average value. The Wind Erosion Equation was intended to estimate annual soil loss from small or large fields and does not provide any indication of the suspended fraction or how such emissions might vary throughout the year.

1.3.3 Modified Wind Erosion Equation

A simplified version of the Wind Erosion equation was suggested by Cowherd and others (1974) for fugitive dust emission estimates from exposed areas. The modified Wind Erosion Equation assumes that fugitive dust emissions or the fraction of the soil that remains suspended is a constant fraction of the total soil loss. This technique has historically been the basis of estimates for windblown fugitive dust used by, among others, the U.S. EPA Region VIII, Wyoming Department of Environmental Quality, and the Colorado Air Pollution Control Division.

1.3.4 Areas of Finite Availability of Erodible Material

The techniques mentioned above were developed for agricultural fields characterized by a relatively unlimited reservoir of erodible material. Experiments conducted at western surface coal mines (PEDco, 1984) indicated that exposed overburden and many natural surfaces can be characterized by a finite availability of erodible material. Such surfaces were often nonhomogeneous with large quantities of nonerodible elements (clumps of vegetation, stones, etc.) or had a surface crust which acts to protect the underlying soil. Windblown emissions from these surfaces occurred only during peak wind gusts and were limited by the frequency at which these surfaces were disturbed, replenishing the supply of material available for suspension (Cowherd, et al., 1984).

1.3.5 Additional Research

D.A. Gillette and his colleagues at the National Center for Atmospheric Research have conducted a number of laboratory and field experiments investigating: airborne particle size distributions (Gillette, et al., 1974), vertical fluxes of fine (<20 μm) particulate (Gillette, 1976), and threshold velocities for suspension (Gillette, et al., 1980 and 1982; Gillette, 1983). Several conclusions were supported by observations from these studies:

- suspension was not measured in the absence of saltation and only occurred when the wind stress was above some minimum threshold value;

- airborne size distributions were found to vary with the dry aggregate structure, moisture content, and crustal properties of the material; and,

- vertical mass flux of suspended particulate increased with wind speed and was greater over materials with larger suspendible mass fractions.

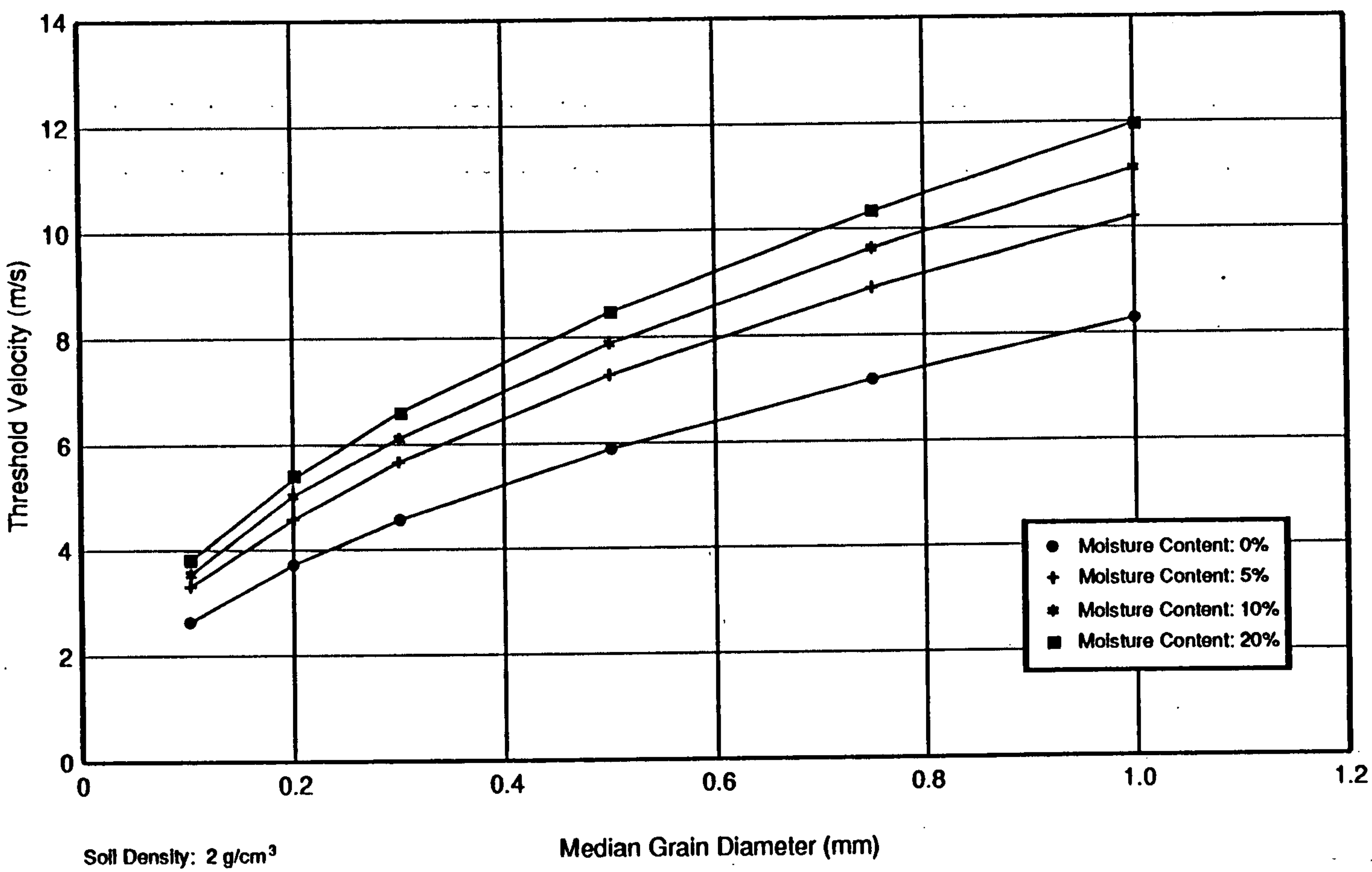
The concepts of a limited erosion potential and a threshold for erosion were employed in the techniques outlined by Cowherd (1974) for rapid assessment of surface contamination sites. Soils were classified into either limited or unlimited erosion potential groups based on the threshold velocity for erosion, and different methods were used to predict annual and maximum short-term PM_{10} emissions. Threshold velocities were predicted based on an empirical fit to soil sieve analysis data. Emissions from surfaces with unlimited potential were based on the frequency of disturbance and the peak wind gust (fastest mile) between disturbances. A correction was applied for surface moisture and vegetation cover. For highly erodible soils, PM_{10} emissions were based on an integral of the wind speed distribution above the threshold velocity.

Travis (1975) developed a model combining several aspects of the Wind Erosion Equation with more recent data from Gillette's research. The concept of a minimum shear stress threshold to initiate saltation was introduced and airborne mass transfer was predicted to occur only for those wind events exceeding this threshold. Vertical dust suspension was described as a variable function of the saltation mass flux dependent on the mass percentage of soil particles less than 20 μm. Figure II-1 shows threshold wind velocities necessary to initiate saltation at varying soil moisture concentrations.

A modified version of the Travis combined suspension model was incorporated into the emission algorithms of the Nuclear Regulatory Commission's models UDAD (Momeni, et al., 1979) and MILDOS (Strenge and Bander, 1981). Emission algorithms were employed to predict windblown dust emanating from uranium mill tailing piles. Travis's techniques were simplified somewhat in these applications and threshold velocities from suspension were predicted based on Bagnold's relationship for the initiation of saltation with a modification to account for influence of moisture.

Comprehensive articles by Smith and others (1982, 1983) reviewed 15 previously published models for estimating the suspension of particles by wind, including the modified Wind Erosion Equation and UDAD models. Sensitivity tests were employed by varying the parameters of the emission models when applied to windblown emissions from a thorium ore stockpile. Of the models that were examined, the reviewers preferred the behavior of the Travis combined suspension and UDAD emission models.

In addition to the general literature, a review of previous windblown dust studies was conducted for the RI/FS Bunker Hill Superfund site (PEDco, 1975; PES, 1979; von Lindern, 1986; CH2M Hill, 1972). This material was evaluated to determine applicability to the Rocky Flats site. Material from the Bunker Hill site was chosen for review because of the extensive amount of previous Dames & Moore work on site remediation plans, methods, and documentation. With the exception of CH2M Hill (1987), the site-specific windblown dust studies reviewed for Bunker Hill used the Modified Wind Erosion Equation to predict emission rates. The CH2M Hill (1987) study used the equation for wind erosion



Soil Density: 2 g/cm^3
Roughness length: 10 cm

Figure II-1
Threshold Wind Velocity
for Initiation of Saltation

from active storage piles published in the EPA's AP-42 document (1985) to estimate emission factors.

1.3.6 Proposed Techniques for Predicting Site Specific Windblown Contamination at RFP

The review of the literature has indicated that there are many varied and vastly different techniques available for predictions of windblown dust. However, this review has indicated that none of the methodologies examined could clearly be judged superior in light of limited existing data for application to the Rocky Flats site. Two techniques were identified as being useful to predict site-specific windblown contamination at the Rocky Flats Plant. It is proposed that these two independent techniques, along with a suitable dispersion model, be applied and evaluated using on-site air quality data.

It is proposed that one of the techniques for prediction of windblown dust emissions be the modified Wind Erosion Equation. This methodology was selected for the following reasons:

- the method has formed the basis of previous studies at various sites, and projected field programs can be easily tailored for collection of data specifically for its application;
- the method has regulatory precedence for use in fugitive dust assessments; and
- the relationships used by the technique were based on years of extensive data and research.

While the modified Wind Erosion Equation has been applied to a wide variety of fugitive dust problems, reservations were apparent about several aspects of this approach. The development of the method was based primarily on data collected for tilled agricultural fields and its applicability to natural surfaces, exposed areas, or storage piles is questionable. In addition, this technique involves an almost ad hoc assumption regarding the suspended fraction of the total soil loss, and this ratio has been observed to be quite variable. Finally, this approach was developed for long-term estimates based on an annual climatic factor. The derivation of an hourly, daily, or seasonal climatic factor using the same basis is not straight forward, primarily because of the difficulties introduced by short-term moisture effects.

In order to obtain an independent estimate of windblown dust emissions from the exposed areas of the Rocky Flats site, it is proposed that the algorithms of the UDAD model also be utilized. This technique is more contemporary, using the concepts of a threshold velocity and a variable suspension to saltation flux ratio. The UDAD windblown dust emission treatment has also had favorable reviews in the literature. However, the model is highly parametric and depends on several variables which are difficult to estimate. In addition, many aspects of the formulation are based on only limited experimental data.

Descriptions of the modified Wind Erosion Equation and UDAD suspension model are provided in Sections 1.3.7 and 1.3.8, respectively.

1.3.7 Discussion of the Modified Wind Erosion Equation

The modified Wind Erosion Equation proposed for use at the RFP, is an adaptation of techniques developed by the U.S. Department of Agriculture to predict topsoil losses from agricultural fields based on decades of research. The specific equation that will be applied was suggested by Cowherd and others (1974), namely:

$$E = AIKCL'V' \qquad \text{(eq. II-1)}$$

where:

- E = suspended particulate (TSP) fraction of wind erosion losses (ton/acre/yr),
- A = portion of total wind erosion losses that would be measured as suspended particulate, estimated to be 0.025 (Cowherd, 1974),
- I = soil erodibility (tons/acre/yr),
- K = surface roughness factor,
- C = climatic factor,
- L′ = unsheltered field width factor, and
- V′ = vegetative cover factor.

The factor I represents the basic erodibility of a large, flat, base field in a windy, hot, dry climate; K, C, L′ and V′ are reduction factors representing ridged (furrowed) soil surface, a climate less conducive to wind erosion, a smaller or sheltered field, and vegetation, respectively.

Chepil (1945a) reports that the amount of material transported in suspension varied from 3 to 38 percent. However, Cowherd (1974) argues that the material moved by "suspension" is not equivalent to the portion that remains as suspended particulate, because the former contains a significant amount of material that settles out near the point of origin. Based on particle size distribution data from windblown areas, Cowherd suggested a value of 2.5 percent which is within the respective ranges of 1 to 4.1 and 0.3 to 10 percent reported by Baskett (1983) and PES (1979). The 2.5 percent value has also historically been used by the Wyoming Department of Environmental Quality and the U.S. EPA Region VIII for applications involving western surface coal mines (Baskett 1983).

The factor in the modified Wind Erosion Equation can be estimated from tabulated data developed for the purpose for a large area such as a county. In order to be more site-specific, the approach that is proposed for use for the Rocky Flats windblown dust source inventory is to characterize each dust source with site-specific sampling data and then use these data to estimate values for the factors.

1.3.8 Modified UDAD Equation

This section describes the proposed alternative technique for the prediction of the windblown dust based on the algorithms contained in the UDAD model (Momeni, et al., 1979). Emission estimates for tailings piles in the UDAD model are based on a simplified adaptation of the Travis combined suspension model (Travis, 1975). This technique uses the concept of threshold wind velocity or surface stress where the vertical flux of a contaminant is a variable fraction of the saltation mass flux. Emission rates will be calculated as functions of wind speed, surface roughness, material density, dry aggregate material grain diameter distribution, and water content specific to the RFP. The vertical flux of total particulate mass less than 20 μm is given by:

$$q_v = q_h \frac{c_v}{c_h} \frac{1}{u_{*t}^{3}} \left[\left(\frac{u_*}{u_{*t}} \right)^{\frac{p}{3}} - 1.0 \right] \qquad \text{(eq. II-2)}$$

where:

q_v = vertical flux of particulate (< 20 μm) material ($g/(m^2s)$),

q_h = horizontal flux of particulate material (g/(m-s)),

c_v = coefficient of proportionality for vertical flux, $2x10_{-2}$ ($g/(m^2s)$),

c_h = empirical constant to relate shear velocity to horizontal flux, 100 (gs^2/m^4),

u_* = shear or friction velocity (m/s),

u_{*t} = threshold shear velocity (m/s), and

p = percent of material mass less than 20 μm in diameter.

The values of c_v and c_h were derived by Travis based on the data collected by Gillette for several types of highly erodible soils. The friction velocity is specified assuming a logarithmic wind profile via:

$$u_* = \frac{0.4u(z)}{\ln\left(\frac{z}{z_o}\right)} \qquad \text{(eq. II-3)}$$

where:

u(z) = the wind velocity (m/s) at height z (m), and

$z_o =$ the surface roughness length (m).

In the UDAD wind suspension model the threshold shear velocity for the initiation of saltation is specified using a modified version of Bagnold's theoretical relationship:

$$u_{*t} = c_t(1.8 + 0.6\log_{10}(W))\sqrt{2r_s g \frac{P_s - P_a}{P_a}} \qquad \text{(eq. II-4)}$$

where:

$c_t =$ dimensionless coefficient of 0.1 in value,
$P_s =$ density of the material (kg/m^3),
$P_a =$ density of the air (kg/m^3),
$g =$ gravitational acceleration (m/s^2),
$r_s =$ average particle radius of the eroding material (m), and
$W =$ water content of material, percent by weight.

The form of the equation above is supported by both wind tunnel experiments conducted for a variety of surfaces and particles sizes and by field experiments for dry highly erodible soils (Gillette, 1982). Note that the value of c_t assumed in the UDAD model is in close agreement with the value of 0.13 found by Gillette (op. cit.). The effect of the moisture correction term on the threshold velocity introduced in the UDAD model is demonstrated in Figure II-1 using Equations II-3 and II-4 for several different soil types.

The horizontal saltation flux in the UDAD model is represented by the following equation which was reported by Gillette (1976):

$$q_h = c_h u_*^2 (u_* - u_{*t}) \qquad \text{(eq. II-5)}$$

The horizontal flux is assumed to be negligible during periods when the wind velocity is below the threshold value. The majority of the relationships above were based on field experiments utilizing a portable wind tunnel or were developed in the laboratory. Such experiments involved the application of a relatively constant wind velocity during the course of the measurements. Actual winds observed during an hourly period can be expected to be more variable, such that short-term gusts could produce suspension even though the average value is less than the threshold. In order to incorporate such effects an integral from Equation II-2 weighted by an estimate of the wind speed probability density function is developed:

$$q_{ave} = \int_0^{\infty} q_v(u)p(u)du \qquad \text{(eq. II-6)}$$

where:

q_{ave} = average hourly vertical mass (< 20 μm) flux (g/(m^{2}s)), and
P(u) = hourly wind speed probability density function (s/m).

The hourly wind speed probability distribution function is assumed to be described by a normal curve, namely:

$$P(u) = \frac{1}{\sqrt{2\pi}\,\sigma_u} e^{\left[\frac{-(u-u_{ave})^2}{2\sigma_u^2}\right]} \qquad \text{(eq. II-7)}$$

where:

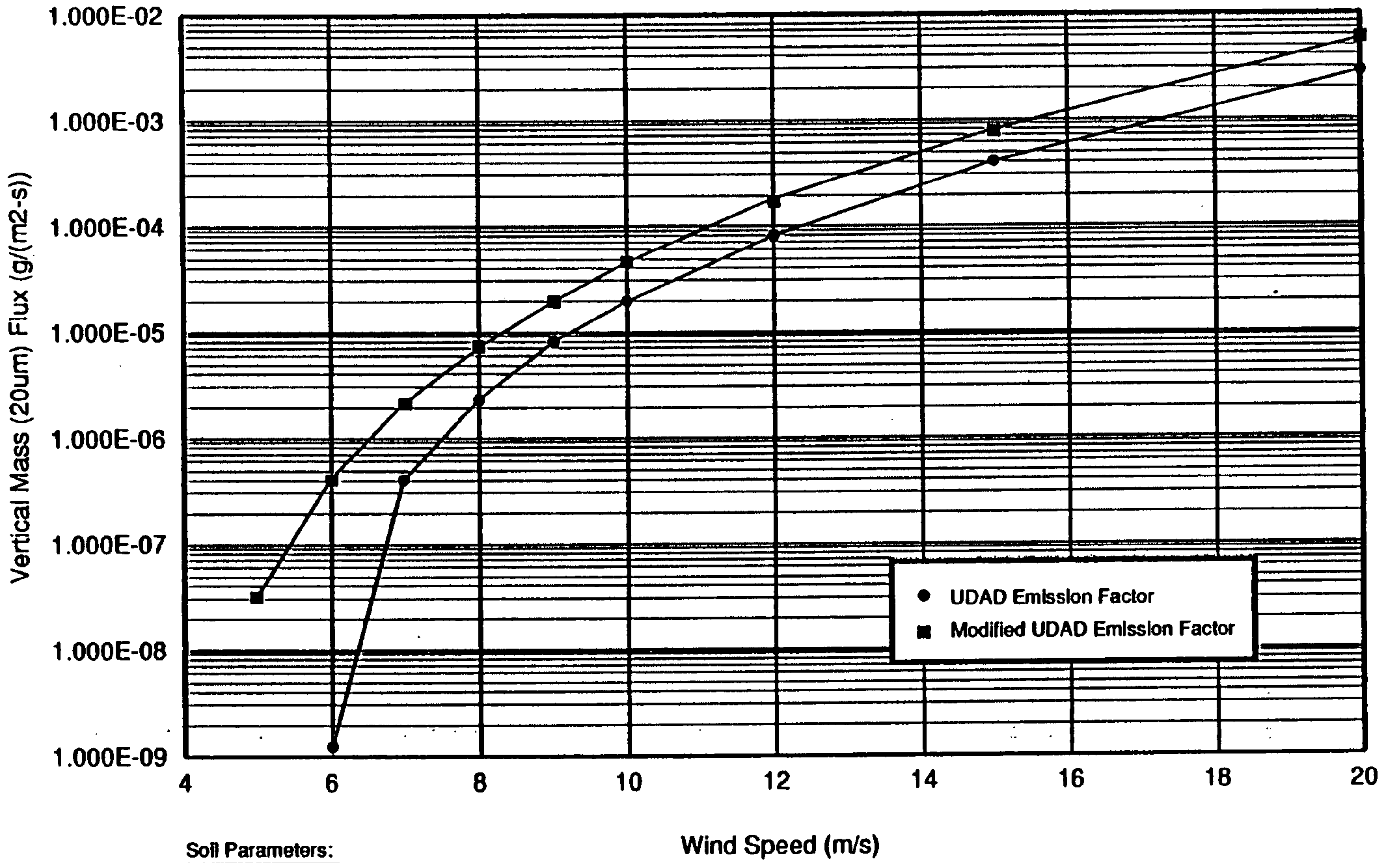
u_{ave} = average hourly wind speed (m/s), and
σ_u = hourly standard deviation of wind speed (m/s), approximated by σ_u = 2.3u. which is with in the range of values commonly observed

for near neutral condition (Arya, 1984). For a z_o of about 0.1 m, σ_u/u_{ave} is approximately 0.2.

An example of the differences introduced by integrating with the probability density function are exhibited in Figure II-2. This figure displays the original UDAD emission factor predicted by Equation II-2 with Equation II-6 and II-7, for a dry soil with characteristics similar to those predicted for the Rocky Flats site. This example demonstrates that the modified relationships predict substantially higher values, particularly near the threshold velocity. For higher wind speeds, the ratio of the modified to the original UDAD emission factor approaches a constant value which depends primarily on σ_u/u_{ave}.

Equations II-2 through II-7 form a closed set for the prediction of the 20 μm fraction of the vertical mass flux given the input variables: average hourly wind speed, surface roughness length, moisture content, soil density, and the soil's dry aggregate structure. In order to predict the total mass flux for all airborne size fractions and to account for vegetative cover, we propose to modify Equation II-7 with:

$$q_{tot} = \frac{100(1-V)q_{ave}}{f_{20}} \qquad \text{(eq. II-8)}$$



Soil Parameters:

Median Grain Size: 0.5mm
Fraction <20mm: 10%
Moisture Content: 0%
Threshold Velocity: 5.9 m/s

Figure II-2
UDAD vs. Modified UDAD Emission Factor

where:

q_{tot} = average hourly vertical mass flux for all particulate sized ($g/(m^2s)$);

f_{20} = portion of suspended particulate size distribution less than 20 μm in diameter (percent); and

V = vegetative cover fraction.

The methods employed to estimate values for the variables required for application of the modified UDAD emission relationships described above will be presented in Section 2.3.

1.4 Aerodynamic Properties of Contaminants

Appendix B contains information derived from RFP respirable particle size and resuspension studies. Studies have shown that "As a group, particles less than or equal to 100 μm aerodynamic equivalent diameter include those that can be suspended by and transported in the wind and those that can be inhaled...Particles in the 30 to 100 μm diameter range will often settle within a few hundred feet of the source (EPA 1985a), while those particles less than or equal to 30 μm diameter can be transported considerable distances downwind. To estimate inhalation exposure, only the inhalable fraction of suspended particulates (less than or equal to 10 μm in diameter) must be considered" (EPA 1988a). It is proposed that this EPA guidance be applied when estimating the risk from windblown contamination.

1.5 Chemical and Physical Properties of the Waste Material Affecting Emissions

Table 1.1 provides a summary of the effects of chemical and physical properties on emission rates.

2.0 NATURE OF CONTAMINANTS

It is proposed that a determination of the nature of contaminants involved will be based on an evaluation of the following information:

2.1 Contaminant Levels

Contaminant levels potentially available to contribute to windblown contamination will be ascertained by the RCRA Facility Investigation/Remedial Investigation (RFI/RI) process as a separate task.

2.2 Toxicity of Contaminants

The toxicity and carcinogenic nature of contaminants will be ascertained from available research, emphasizing human or animal studies data as recommended by the EPA, as a separate task.

2.3 Windblown Dust Inventory

It is proposed that the emission factor relationships for windblown dust described in Section 1.3 be applied to sites at the RFP to develop a local windblown inventory. Physical and chemical data that are needed to

TABLE 1.1
CHEMICAL AND PHYSICAL PROPERTIES OF THE
WASTE MATERIAL AFFECTING EMISSIONS

PROPERTY	EFFECT
Saturation Concentration	The waste will tend to reach equilibrium with the soil vapor. If sufficient waste is present, the equilibrium concentration within the air-filled voids of the soil matrix will reach saturation. Because the rate of emission to the atmosphere is directly proportional to the soil vapor concentration, the emission rate will increase as saturation concentration increases.
Diffusion Coefficient	Compounds with high overall diffusion coefficients will be emitted at higher rates than those with lower diffusion coefficients via increased transport, on a relative basis. The overall diffusion coefficient may be comprised of diffusion through the soil-water interface, soil-air interface, soil, water, air, and soil vapor.
Molecular Weight	Lower molecular weight compounds typically have higher volatilization and diffusion coefficients. Other compound characteristics may predominate. Molecular weight is used to determine diffusion rates in some predictive models.

TABLE 1.1 (Cont'd)
CHEMICAL AND PHYSICAL PROPERTIES OF THE
WASTE MATERIAL AFFECTING EMISSIONS

PROPERTY	EFFECT
Partial Pressure of Constituents	High partial pressure increases the emission rate of a species by increasing its soil vapor concentration.
Weight Fraction	An effect similar to partial pressure, it is used as an input to some predictive models. Not as important as Henry's Law constant.
Combination of Constituents	This increases the complexity of the emissions process and determines the emission rate. It may change over time as more volatile species are lost.
Concentration of Waste	Increasing waste concentration increases the emission rate for dilute wastes by increasing the vapor pressure and, therefore, vapor concentration.
Henry's Law Constant	This is used to determine diffusion coefficients. A high Henry's Law constant produces a higher diffusion rate.
Porosity	One of the controlling factors for diffusion through the soil. Emission rates typically increase with increasing soil porosity. Total porosity, i.e., dry soil, may represent worst-case conditions for predictive models. Air-filled porosity may be more realistic parameter for many sites.

TABLE 1.1 (Cont'd)
CHEMICAL AND PHYSICAL PROPERTIES OF THE
WASTE MATERIAL AFFECTING EMISSIONS

PROPERTY	EFFECT
Adsorption/Absorption Properties of Soil	Soil with high sorption properties will reduce the vapor density of the sorbed compounds and, therefore, the emission rate. The effect may be minimal where high waste concentrations saturate the sorption sites. The effect may be reversed causing increased emissions.
Soil Moisture	Its effect varies. High moisture will reduce the air-filled porosity, with pores being filled under worst-case conditions and, therefore, should reduce the emission rate. Moisture may be preferentially adsorbed by the soil, releasing volatiles and increasing the emission rate. Drying of soil may increase available sorption sites. Moisture is required for the wick effect.
Capillary Effect	Soil moisture may draw waste constituents to the surface through the soil pores. This process can increase the concentration of the constituents at the surface and, therefore increase the emission rate.

TABLE 1.1 (Cont'd)
CHEMICAL AND PHYSICAL PROPERTIES OF THE
WASTE MATERIAL AFFECTING EMISSIONS

PROPERTY	EFFECT
Particle Size Distribution	This affects the total soil porosity and soil pore continuity. Increased soil pore continuity increases the emission rate. A higher percentage of fine particles will typically increase particulate emissions.
Organic Content of Soil	High organic content will increase the sorptive characteristics of the soil and reduce the emission rate. High organic content also will increase microbial action.
Microbial Activity	Its effect varies. It may reduce the emission rate by biological reduction of the waste present. It also may increase the emission rate due to gas formation which carries volatile species to surface.
Depth of Landfill Cover	Emission rates decrease with increasing depth (thickness) of cover as the diffusion path increases. For an open dump or landfill, the cover thickness is zero.
Compaction of Landfill Cover	Increasing compaction reduces the soil porosity and disrupts continuity of the soil pores, thereby reducing the emission rate.

TABLE 1.1 (Cont'd)
CHEMICAL AND PHYSICAL PROPERTIES OF THE
WASTE MATERIAL AFFECTING EMISSIONS

PROPERTY	EFFECT
Ground Cover	Soil cover, typically vegetation, will reduce particulate emission by reducing the erodibility of the soil. It also will help hold soil moisture, which reduces the air-filled porosity and reduces volatile emissions.
Size of Landfill/Impoundment	The emission rate is directly proportional to the size of the landfill or lagoon.
Amount of Exposed Waste	Emission will increase when waste is exposed at the surface, both due to volatilization and wind erosion.
Water Depth in Impoundment	Water overlying waste will act as a cover. Diffusion through water may control the emission rate.
Aeration of Impoundment	Aeration increases emission of volatile and particulates with increasing volume of air used and/or agitation. The effect is due to air stripping of volatiles and bulk transport of liquid particles.
Temperature	Increasing temperature increases the volatilization rate for organic species and, therefore, the emission rate. Increasing temperature reduces soil moisture, increasing air-filled porosity and the emission rate.

TABLE 1.1 (Cont'd)
CHEMICAL AND PHYSICAL PROPERTIES OF THE
WASTE MATERIAL AFFECTING EMISSIONS

PROPERTY	EFFECT
Wind	Wind removes the volatilized compound concentration in the boundary layer over the site, maintaining the driving force for volatilization. Increasing wind speed reduces the boundary layer over the site. Wind causes turbulence within the boundary layer, providing the driving force for surface soil/waste erosion and increasing particulate emission rate.
Cloud Cover	Increased cloud cover reduces solar heating of the surface and, therefore, the volatilization rate from surface. It also affects wind stability.
Precipitation	Emissions are reduced by reducing the air-filled soil porosity. It may increase landfill emission by displacing soil vapor from soil voids. It may increase surface water and air emissions by floating waste constituents to the surface. Precipitation increases agitation of the lagoon surface, potentially increasing emissions, but it also increases water depth over waste in the impoundment.

TABLE 1.1 (Cont'd)
CHEMICAL AND PHYSICAL PROPERTIES OF THE
WASTE MATERIAL AFFECTING EMISSIONS

PROPERTY	EFFECT
Humidity	Increasing partial pressure of water vapor in air reduces the capacity for some types of volatilized material. It may reduce air-filled soil porosity.
Barometric Pressure	Changing barometric pressures cause bulk flow of soil vapor into/out of soil. The overall net effect is to increase the emission rate. The effect increases with frequency and scale of barometric changes.

characterize potential dust sources, and the techniques to be used to derive the various input parameters are proposed for both the Modified Wind Erosion Equation and for the modified UDAD erosion models. Table 1.2 summarizes the proposed data collection tasks necessary to determine local, site-specific values for variable parameters.

2.3.1 Development of a Spatial Subdivision System

It is proposed that the spatial portion scheme suggested by Von Lindern (1986) be adapted for application to the Rocky Flats site for the purpose of developing a windblown dust inventory. A separate spatial subdivision system is proposed for dispersion modeling, as discussed in the last section of Part II. Von Lindern subdivided the Bunker Hill Superfund site for a study of potential recontamination of remediated and uncontaminated areas by windblown dust. It is recommended that a Rocky Flats site subdivision be accomplished early on in the initial soil sampling phase of a particular remedial investigation. This will enable development of detailed, IHSS-specific spatial representations of possible on-site sources of windblown dust, including an estimation of the size of each subdivision.

2.3.2 Vegetative Cover Studies

The assessment of dust sources will incorporate data collected as part of the vegetation studies. The vegetative cover data must be developed in terms of classes of percent cover; for this analysis the midpoint of each range will be used as the representative vegetative cover.

TABLE 1-2

TASKS REQUIRED TO DETERMINE SITE SPECIFIC VALUES FOR VARIABLE PARAMETERS

TASK	APPLICABLE MODEL	VARIABLE PARAMETER
Development of a spatial subdivision system	Modified Wind Erosion Equation/ UDAD	(Needed to calculate all parameters)
Soil contamination sampling	Modified Wind Erosion Equation	To calculate hazardous contaminant emission friction
Percent vegetation cover studies	Modified Wind Erosion Equation/ UDAD	V′ V
Geophysical Survey		
1) Determination of particle size fractions	Modified Wind Erosion Equation/ UDAD	I P, r_s, f_{20}
2) Description of roughness of ground surface	Modified Wind Erosion Equation	K
3) Size and topography of the source for determining the unsheltered field width factor	Modified Wind Erosion Equation	L′
4) Water content of the soil	UDAD	W

TABLE 1-2 (CONT'D)

TASKS REQUIRED TO DETERMINE SITE SPECIFIC VALUES FOR VARIABLE PARAMETERS

TASK	APPLICABLE MODEL	VARIABLE PARAMETER
Meteorological Monitoring		
1) Wind Speed	Modified Wind Erosion Equation/ UDAD	C u
2) Temperature	Modified Wind Erosion Equation	C
3) Precipitation	Modified Wind Erosion Equation	
4) Air density	UDAD	P_a
5) Aerodynamic Surface Roughness Length	UDAD	z_o

It is proposed that dust source zone boundaries be digitized from a base map of the site and the percent of vegetative cover cross tabulated. Midpoint percentages will then be area weighted within each dust source zone, and the resultant mean percent cover determined. Physical characteristics of any exposed soil area (or subdivision, as discussed in Section 2.3.1) will be determined.

2.3.3 Dust Source Characterization Required for the Modified Wind Erosion Equation

The data required to characterize windblown dust sources for estimating emission factors with the modified Wind Erosion Equation include the following:

- sieve analysis of soil for determining the soil erodibility term, I;
- amount and type of vegetation for determining the vegetative cover factor, V′;
- descriptions of ground surface to determine the surface roughness factor K;
- size and topography of the source for determining the unsheltered field width factor, L′;
- mass fractions of heavy metals contaminants in the silt fraction to calculate metal emissions; and,
- climatological data including wind speed, temperature, and precipitation in order to determine the climate factor, C.

Values for I, K, L′, and V′ are required for the application of the modified Wind Erosion Equation. As these parameters were intended to be based on data available for agricultural fields, several assumptions regarding their derivation were necessary for the purposes of the emission inventory. The vegetative cover factor was originally based on the amount of vegetative residue in the soil. For application at Rocky Flats, V′ may be assumed to be the fraction of the total source area not covered by vegetation, buildings, snow cover, or pavement and is used in an analogous fashion as the (1-V) term in Equation II-8.

The soil erodibility term (I) in the modified Wind Erosion Equation depends on the mass fraction of material passing through a 0.84 mm sieve (#20 mesh). In cases where soil sampling cannot be performed, the sieve fractions for dust sources must be approximated by using the sieve fractions from adjacent hillsides whose physical descriptions (of the type of soil) most closely resemble those of the unsieved dust sources. For all areas determined to have a significant potential for windblown dust, a grain size analysis must also be performed. For all of these analyses, a #20 mesh sieve should be employed and the soil erodiblity (I) taken as a function of the results. In addition to the fraction greater than 0.84 mm required for estimates of erodibility in the modified Wind Erosion Equation, the algorithm based on the UDAD suspension model needs the fraction less than 20 μm (p) and an indication of the representative size of a saltating particle (r_s). The latter may be estimated from the median value found in the sieve analysis. The median value will provide a good indication of the representative grain size for soils in many areas of concern, but will only roughly approximate the more uniform size distribution of some soils.

The surface roughness factor (K) accounts for the resistance of wind erosion provided by ridges and furrows or large clods in an agricultural field. This value is a function of the height and spacing of these ridges and is usually specified according to the crop type. As this parameter ordinarily will not directly apply to the exposed areas at the Rocky Flats site, a value of unity may be assigned for most source areas. Exceptions should be determined on an area-specific basis.

The unsheltered field width factor (L′) in the Modified Wind Erosion Equation accounts for the protection offered by a wind break or structure located at the upwind edge of a field. The rate of erosion is near zero at the windward edge of the exposed area and increases with fetch until the maximum rate of soil movement is achieved. The more erodible the soil, the shorter the distance required to reach the full erosion potential of the surface. The sheltering effects of buildings and topography must be incorporated in the emission inventory by subjectively assigning different values to L′. As an example, for source areas located on the lee side of a ridge, L′ may be given a value of 0.9 corresponding to a field width of about 1000 m and a moderately erodible soil. For source areas located in a narrow valley, a value of 0.8 might be assigned. To account for the protection offered by buildings, especially if there is further protection from a valley location, L′ may be set to a value of 0.5 (Dames & Moore, 1990).

Heavy metal or chemical constituent mass emission rates for the exposed source areas will be estimated by multiplying the total mass emission rate by concentration estimates based on the laboratory analysis from the minus 75 μm fraction. In the case where chemical data for the minus 75 μm samples cannot be made available, analyses from the total samples should be used. A determination must be made in the initial soils investigations whether concentrations for the fraction less than 75 μm are similar to those based on the total sample.

2.3.4 Dust Source Characterization Required for the UDAD Equation

In addition to the above data, the following information is required for application of the alternative emission factor relationship based on the UDAD suspension algorithm:

- sieve analysis of soil for determining the portion of the material less than 20 μm, p, and for estimates of the average size of the saltating particles, r_s;
- assumptions regarding the portion of suspended particulates size distribution less than 20 μm in diameter, f_{20};
- vegetative cover fraction, V;
- water content of the material, W; and
- meteorological data including wind speed (u), density of the air (p_a), and an estimate of the aerodynamic surface roughness length (z_o).

All of the above-listed information will need to be determined on a source-specific basis with the exception of the climatological data. The data sources and the method of estimating emission factors for each dust source are discussed below. Particle size distribution data from the literature are presented in Appendix B, and a summary of available meteorological data is included in Appendix A.

2.3.5 Climatological Data

Climatological data are required for estimates involving both emission factor relationships discussed in Section 2.3. Emission estimates in dispersion modeling analyses to be performed to develop the dust inventory for each site will vary with hourly wind velocity and will also depend on a moisture parameter. With the exception of those areas with excessive surface moisture or subject to dust control measures involving the application of water, these variables will ordinarily be the same for most source subdivisions. Wind velocity will be obtained directly from the on-site monitoring program. It is proposed that moisture parameters be derived according to the techniques outlined in the remainder of this section.

1) **Climate Factors for the Modified Wind Erosion Equation:** The influences of local meteorology on soil loss using the modified Wind Erosion Equation must be incorporated with a climatic factor. The climatic factor (C) should be estimated for the Rocky Flats site following the relationship that soil loss varies directly with the cube of wind velocity and inversely with the square of the effective moisture content of the material (Woodruff and Siddoway, 1965). The actual soil moisture content of each source should be determined according to Thornthwaites Precipitation-Evaporation (P/E) index.

2) **Climate Factors for the UDAD Suspension Model:** For the modified UDAD suspension model, windblown emissions only occur when winds are above a threshold velocity for a given soil structure. The

prediction of the surface shear stress required for initiation of saltation is dependent on the local wind speed, surface roughness length, and moisture content. When this threshold is exceeded, suspension is approximately proportional to the cube of wind speed depending on the 20 μm fraction of the erodible material.

Following Woodruff and Siddoway, an annual climatic factor can be expressed by:

$$C = \frac{0.345\, U^3}{(P/E)^2} \qquad \text{(eq. II-9)}$$

where:

P/E = Thornthwaites precipitation - evaporation index. An annual estimate for P/E is defined as 10(P/E) or ten times the sum of the monthly P/E indices;

U = wind speed expressed in (mph);

P/E = monthly index is given by:

$$P/E = 11.15\left[\frac{P}{T-10}\right]^{10/9} \qquad \text{(eq. II-10)}$$

P = monthly average precipitation (inches), and

T = monthly average temperature (°F).

It is expected that relatively high average wind speeds at the Rocky Flats site will give rise to a relatively high annual climatic factor, except where locally sheltering effects from buildings or valley locations are encountered. It can also be expected that seasonal effects will give rise to an increased potential for windblown dust in the dry, late summer months, compared to other seasons of the year. Although monthly average winds vary, seasonal differences in the climatic factor can primarily be attributed to differences in the P/E index.

3) **Site-Specific Effects of Climate on the Potential for Windblown Contamination:** The annual and seasonal climatic factors assumed above would suggest that the local climate of the Rocky Flats site is generally conducive to windblown dust. It would appear that wind-generated suspension would typically be encountered in many episodes each year but especially during the drier months. It is expected that for long-term predictions of total mass that windblown dust plays a significant role when compared to other fugitive and particulate sources in the area. In terms of several of the contaminants of concern, local windblown transport may be the dominant mechanism. Therefore, it is considered important that the emission relationships used for windblown dust be able to support the variation exhibited by short-term episodes. In order to resolve short-term episodes of windblown dust, emission rates to be used in future dispersion modeling studies will need to vary on an hourly basis.

4) **Soil Moisture Content:** Incorporation of an hourly emission rate dependent on the wind speed is relatively straightforward, but

prediction of the influence of moisture will be more difficult. Several possibilities should be considered for the latter including:

- an annual average P/E index or constant moisture content;
- a seasonally variable moisture parameter;
- a moisture parameter updated daily dependent on the conditions of the preceding months; and
- prediction of soil moisture content using an infiltration model based on precipitation, predictions of evapotranspiration, and the infiltrative and storage capacities of the soil.

Source areas may be located near standing water, subject to the application of water for dust control, or may have a moisture content above that predicted using climatological methods. For these areas, the climatic factor (C) may be reduced by 50 percent to account for this excessive moisture. This credit is commonly used by the U.S. EPA to account for the application of water for dust control measures. Based on the concept that erodibility is related to the inverse of the moisture content squared (Equation II-9), a 50 percent reduction in erodibility would correspond to only a 41 percent increase in the moisture content of these sources.

3.0 MAGNITUDE OF CONSTITUENTS RELEASES FROM SITES AT RFP

The probable magnitude of windblown releases will be evaluated based on the following factors:

3.1 **Extent of Contamination:** The physical area and overall size of the contaminated area that is exposed or will be exposed along with data developed during the RFI/RI process will be used to determine the possible extent of the contamination.

3.2 Types of Remediation to be Employed

Separate remediation methods are proposed for each of the IHSSs at the RFP. The magnitude of potential releases of windblown material will depend on the method selected; considerations which will be taken into account in determining releases associated with each remediation plan.

If air strippers are to be used, the following parameters will be evaluated to determine their effect on the emissions from air stripping operations:

Groundwater volatile organic concentration;
Volatility (Henry's Law Constant) of the volatile organic;
Groundwater temperature;
Air temperature;
Air/water contact time;
Air/water ratio; and use and efficiency of control device.

For remediation technologies which employ soils handling, Table 1.3 contains a list of parameters that may effect the emissions potential during soils handling at a given site.

The key parameters affecting particulate matter and volatile organic emissions during stabilization/solidification are listed in Table 1.4. In general,

TABLE 1.3
IMPORTANT PARAMETERS IN DETERMINING AND CONTROLLING EMISSIONS FROM SOILS HANDLING

Parameter	Typical Importance to Emission Level: Particulates/Metals	Typical Importance to Emission Level: Volatile Organics
Meteorological Conditions		
Wind Speed	Medium	Medium
Wind Direction/Variability	Low	Low
Temperature	Low	Medium
Relative Humidity	Low	Low
Barometric Pressure	Low	Low
Precipitation	High	Medium
Solar Radiation	Low	Low
Operating Characteristics		
Area of Working Face	Medium	High
Agitation Factor	High	High
Drop Height	Low	Low
Storage Pile Geometry	Medium	Low
Available Soil Cover	High	High
Soil/Waste Characteristics		
Physical Properties		
Silt Content	High	Low
PM-10 Content	Low	Low
Density	Low	Medium
Permeability	Low	High
Moisture Content	High	Medium
Organic Fraction	Low	High
Metal Concentrations	High	Low

Source: EPA-450/1-89-003 - January 1989

TABLE 1.4
IMPORTANT PARAMETERS IN DETERMINING AND CONTROLLING EMISSIONS FROM STABILIZATION AND SOLIDIFICATION

Parameter	Typical Importance to Emission Level	
	Particulates/Metals	Volatile Organics
Meteorological Conditions		
Wind Speed	Medium	Medium
Wind Direction/Variability	Low	Low
Temperature	Low	Medium
Relative Humidity	Low	Low
Barometric Pressure	Low	Low
Precipitation	High	Medium
Solar Radiation	Low	Low
Operating Characteristics		
Binder Type	Medium	High
Batch Size	Low	Medium
Waste/Binding Agent Ratio	Medium	Medium
Mixing Time/Efficiency	Low	High
Curing Time	Low	Low
Soil/Waste Characteristics		
Physical Properties		
Silt Content	High	Low
PM-10 Content	Low	Low
Density	Low	Medium
Permeability	Low	High
Moisture Content	High	High
Organic Fraction	Low	High
Metal Concentrations	High	Low

Source: EPA-450/1-89-003 - January 1989

volatile organic emissions will depend on the duration and thoroughness of the mixing, the amount of heat generated in the process, and the amount of soil disturbance.

3.3 Amount of Mechanical Disturbance Expected During Site Remediation

The amount of mechanical disturbance of soil during remediation is dependent on the size of the area to be remediated and the types of activities and amount of time required to achieve the cleanup criteria. Needs of other industries and regulatory agencies have given rise to development of methods for analyzing and quantifying emissions of fugitive dust generated by mechanical operations. Activities which create fugitive dust by mechanical suspension of soil particles in air have been divided into three categories including vehicle traffic on unpaved roads, vehicle traffic on paved roads, and mechanical resuspension by soil movement.

3.3.1 Vehicle Traffic on Unpaved Roads

The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Field investigations have shown that emissions depend on correction parameters (average vehicle speed, average vehicle weight, average number of wheels per vehicle, road surface texture and road surface moisture) that characterize the condition of a particular road and the associated vehicle traffic.

Dust emissions from unpaved roads have been found to vary in direct proportion to the fraction of silt (particles smaller than 75 micrometers in diameter) in the road surface materials. The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200 mesh screen.

The silt content of a rural dirt road will vary with location, and it should be measured. As a conservative approximation, the silt content of the parent soil in the area can be used. However, tests show that road silt content is normally lower than in the surrounding parent soil, because the fines are continually removed by the vehicle traffic, leaving a higher percentage of coarse particles (EPA 1988b).

Unpaved roads have a hard, generally nonporous surface that usually dries quickly after a rainfall. The temporary reduction in emissions caused by precipitation may be accounted for by not considering emissions on "wet" days (more than 0.254 millimeters [0.01 inches] of precipitation).

The following empirical expression may be used to estimate the quantity of size specific particulate emissions from an unpaved road, per vehicle kilometer traveled (VKT), with a rating of A:

$$E = k(1.7)\left(\frac{s}{12}\right)\left(\frac{S}{48}\right)\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{365-p}{365}\right) \quad \text{(kg/VKT)}$$

(Eq. II-11)

where:

E	=	emission factor
k	=	particle size multiplier (dimensionless)
s	=	silt content of road surface material (%)
S	=	mean vehicle speed, km/hr (mph)
W	=	mean vehicle weight, Mg (ton)

w	=	mean number of wheels
p	=	number of dates with at least 0.254 mm (0.01 inches) of precipitation per year

The particle size multiplier, k, in the equation varies with aerodynamic particle size range as follows:

Aerodynamic Particle Size Multiplier for Equation

$\leq 30\ \mu m$[a]	$\leq 30\ \mu m$	$\leq 15\ \mu m$	$\leq 10\ \mu m$	$\leq 5\ \mu m$	$\leq 2.5\ \mu m$
1.0	0.80	0.50	0.36	0.20	0.095

[a] Stokes diameter

The number of wet days per year, p, for the geographical area of interest should be determined from local climatic data.

The equation retains the assigned quality rating, if applied within the ranges of source conditions that were tested in developing the equation, as follows:

Ranges of Source Conditions for Equation

Road silt content (wt. %)	Mean vehicle weight		Mean vehicle speed		Mean no. of wheels
	Mg	Ton	km/hr	mph	
4.3 - 20	2.7 - 142	3 - 157	21 - 64	13 - 40	4 - 13

To retain the quality rating of the equation when addressing a specific unpaved road, it is necessary that reliable correction parameter values be determined for the road in question (EPA, 1988b).

For a contaminant such as plutonium where the respirable cutoff size is defined as 10 μm, this methodology is capable of yielding a value for 10 μm resuspended particulates. Coupling this with air sampling data for 10 μm resuspended particulates will yield a respirable source term for direct input to a dispersion model. Methods to mitigate resuspended particulates are presented in Part I of this plan.

3.3.2 Vehicle Traffic on Paved Roads

A similar procedure can be used for estimating emissions from paved roads. The quantity of dust emissions from a given segment of paved road varies linearly with the volume of traffic. In addition, field investigations have shown that emissions depend on correction parameters (road surface silt content, surface dust loading, and average vehicle weight) of a particular road and associated vehicle traffic.

Dust emissions from industrial paved roads have been found to vary in direct proportion to the fraction of silt (particles equal to or less than 75 microns in diameter) in the road surface material. It has also been found that emissions vary in direct proportion to the surface dust loading. The road surface dust loading is that loose material which can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. Table 1.5 summarizes measured silt and loading values for industrial paved roads (EPA 1988b).

TABLE 1-5
TYPICAL SILT CONTENT AND LOADING VALUES FOR
PAVED ROADS AT INDUSTRIAL FACILITIES

INDUSTRY	NO. OF SITES	NO. OF SAMPLES	SILT (wt. %) Range (R)	SILT (wt. %) Mean (M)	NO. OF TRAVEL LANES	TOTAL LOADING x 10^{-3} Range	TOTAL LOADING x 10^{-3} Mean	TOTAL LOADING x 10^{-3} Units	SILT LOADING g/m^2) R	SILT LOADING g/m^2) M
Copper Smelting	1	3	15.4 - 21.7	19.0	2	12.9 - 19.5 45.8 - 69.2	15.9 55.4	kg/km lb/mi	188 - 400	292
Iron and Steel production	6	20	1.1 - 35.7	12.5	2	0.006 - 4.77 0.020 - 16.9	0.495 1.75	kg/km lb/mi	0.09 - 79	12
Asphalt batching	1	3	2.6 - 4.6	3.3	1	12.1 - 18.0 43.0 - 64.0	14.9 52.8	kg/km lb/mi	76 - 193	120
Concrete batching	1	3	5.2 - 6.0	5.5	2	1.4 - 1.8 5.0 - 6.4	1.7 5.9	kg/km lb/mi	11 - 12	12
Sand and gravel processing	1	3	6.4 - 7.9	7.1	1	2.8 - 5.5 9.9 - 19.4	3.8 19.4	kg/km lb/mi	53 -95	70

From: EPA 1988

The quantity of total suspended particulate emissions generated by vehicle traffic on dry industrial paved road, per vehicle kilometer traveled (VKT) may be estimated with a rating of B or D using the following empirical expression (Cowherd 1979):

$$E = 0.022\ I\left(\frac{4}{n}\right)\left(\frac{s}{10}\right)\left(\frac{L}{280}\right)\left(\frac{W}{2.7}\right)^{0.7} \text{ in (kg/VKT)}$$

(Eq. II-12)

where:

E = emission factor

I = industrial augmentation factor (dimensionless) (see below)

n = number of traffic lanes

s = surface material silt content (%)

L = surface dust loading, kg/km (see below)

W = average vehicle weight, Mg (ton)

p = number of dates with at least 0.254 mm (0.01 inches) of precipitation per year

The industrial road augmentation factor (I) in Equation I-1 takes into account higher emissions from industrial roads than from urban roads. For example, I = 7.0 for a paved industrial roadway which traffic enters from unpaved areas; I = 3.5 for an industrial roadway with unpaved shoulders where 20 percent of the vehicles are forced to travel temporarily with one set of wheels on the shoulder; and I = 1.0 for cases in which traffic travels only on paved areas. A value between 1.0 and 7.0 which best represents conditions for paved roads at a certain industrial facility should be used for I in the equation (EPA 1988b).

The equation retains the quality rating of B if applied to vehicles traveling entirely on paved surfaces (I = 1.0) and if applied within the range of source conditions that were tested in developing the equation as follows:

Silt content (%)	Surface Loading kg/km	No. of Lanes	Vehicle weight Mg	(tons)
5.1 - 92	42.0 - 2000	2 - 4	2.7 - 12	3 - 13

If I is less than 1.0, the rating of the equation drops to D, because of the subjectivity in the guidelines for estimating I.

The quantity of particle emissions in the finer size ranges generated by traffic consisting predominately of medium and heavy duty vehicles on dry industrial paved roads, per vehicle unit of travel, may be estimated, with a rating of A, using the equation:

$$E = K \left(\frac{sL}{12}\right)^{0.3} \quad (kg/VKT) \qquad \text{(Eq. II-13)}$$

where:

E = emission factor
sL = road surface silt loading, g/m^2
K = Particle size multiplier

The particle size multiplier (K) above varies with aerodynamic size range as follows:

Aerodynamic Particle Size Multiplier (K) for Equation 2 (Dimensionless)

$\leq$15 μm	$\leq$10 μm	$\leq$2.5 μm
0.28	0.22	0.081

To determine particulate emissions for a specific particle size range, use the appropriate value of K above.

The equation retains the quality rating of A, if applied within the range of source conditions that were tested in developing the equation as follows:

silt loading, 2 - 240 g/m^2
mean vehicle weight, 6 - 42 Mg (7 - 46 tons)

The following single valued emission factors (Cowherd, 1985) may be used in lieu of Equation II-13 to estimate particle emissions in the finer size ranges generated by light duty vehicles on dry, heavily loaded industrial roads, with a rating of C:

Emission Factors for Light Duty Vehicles on Heavily Loaded Roads

$\leq$15 μm	$\leq$10 μm
0.12 kg/VKT (0.41 lb/VMT)	0.093 kg/VKT (0.33 lb/VMT)

These emission factors retain the assigned quality rating, if applied within the range of source conditions that were tested in developing the factors, as follows:

silt loading, 15 - 400 g/m^2 (0.44 - 12 oz/yd^2)
mean vehicle weight, $\leq$4 Mg ($\leq$4 tons)

Also, to retain the quality ratings of Equations II-3 and II-4 when applied to a specific industrial paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. In the event that site-specific values for correction parameters cannot be obtained, the appropriate mean values from Table 1.5 may be used, but the quality ratings of the equation should be reduced by one level (EPA 1988b).

3.3.3 Mechanical Resuspension by Soil Movement

The other major source of expected mechanical resuspension of soil at RFP during environmental remediation activities is soil movement. Commonly used equipment and procedures include bulldozers moving soil or front-end loaders loading soil into trucks for removal or treatment elsewhere.

1) **Bulldozers:** The tracks and blade of a bulldozer are the sources of emissions. Bulldozer tracks reentrain dirt in much the same manner as wheels, except the grinding action is probably greater. The top and sides of the blade generate emissions as dirt slides off. This is particularly true of the top of the blade, where thin layers of dirt can easily be carried off by the wind.

An emission factor was developed for bulldozing activity on overburden in coal mines, where silt values ranged from 3.7 to 15.1 percent and moisture ranged from 2.2 to 16.8 percent. The emission factor, which includes emissions from both the tracks and the blade, is as shown in the following equation (PEDco, 1981):

$$TSP = \frac{5.7\ s^{1.2}}{M^{1.3}} \qquad \text{(Eq. II-14)}$$

where:

TSP = emissions of total suspended particulate in lb/h
s = silt, percent
M = moisture, percent

2) **Front-End Loaders:** Emissions from front-end loaders emanate from the tracks or wheels as well as the loader bucket. The usual source of emissions from the loader bucket results from spillage as the bucket is being raised. In addition, when the soil from the bucket is dropped into a truck or pile, the soil drop creates two sources of dust: 1) the wind picking up soil

particles from the edges of the mass; and 2) air turbulence causing dust entrainment. In the latter case, the displacement of air out of the truck caused by the mass of dirt moving downward, causes soil already in the truck to rise along with soil from the edge of the dirt mass being dropped.

The emission factor for front-end loader operations given in EPA's Compilation of Air Pollutant Emission Factors (1982) was developed based on material-handling operations at a steel mill. All sources (track, tires, bucket, dump) are represented by this factor, which is given as:

$$E = K(0.0018) \frac{\left(\frac{s}{5}\right) \left(\frac{U}{5}\right) \left(\frac{H}{5}\right)}{\left(\frac{M}{2}\right)^{2} \left(\frac{Y}{6}\right)^{0.33}} \qquad \text{(Eq. II-15)}$$

Where:
- E = TSP emission factor, lbs/ton
- K = Particle size multiplier (dimensionless)
- s = Material silt content percent
- U = Mean wind speed, mph
- H = Drop height, (ft.)
- M = Material moisture content, percent
- Y = Dumping device capacity, yd^3

The silt and moisture terms describe the general dustiness of the material being moved. Three of the variables deal with the material dump cycle. Emissions increase with higher wind speed (blowing of dirt from the dirt mass edges), greater drop height (more turbulence caused by material drop), and smaller bucket size (more dirt mass edge per unit of volume) (EPA 1985a). Mitigation procedures for these emission sources are provided in Part I of this plan.

3.4 Ability to Mitigate Releases

Emissions from certain sites may be controlled through the use of soil covers or barriers, erection of wind breaks, or other methods which do not involve the disturbance of contaminated areas. Proposed methods for management of wastes associated with sites at RFP so as to prevent windblown hazardous materials are provided in Part I of this plan. Table 1.6 summarizes technologies recommended by EPA to control emissions during remediation.

TABLE 1.6
CONTROL TECHNOLOGIES AVAILABLE FOR EACH REMEDIAL OPTION

Remedial Operation	Contaminant	Control Technology
Ground Water Stripping	Hydrocarbons	Condensation Carbon adsorption (disposable) Carbon adsorption (regenerable) Incineration
Soils Handling		
Excavation	Particulates, Hydrocarbons Radionuclides	Water sprays of active areas Dust suppressants Surfactants Windscreen Foam coverings
Transportation	Particulates, Hydrocarbons Radionuclides	Water sprays of active areas Dust suppressants Surfactants Road carpets Road oiling Speed reduction Coverings for loads
Dumping	Particulates, Hydrocarbons Radionuclides	Water sprays of active areas Water spray curtains over bed during dumping Dust suppressants Windscreen Surfactants

TABLE 1.6 (Cont'd)
CONTROL TECHNOLOGIES AVAILABLE FOR EACH REMEDIAL OPTION

Remedial Operation	Contaminant	Control Technology
<u>Soils Handling (Cont'd)</u>		
Storage	Particulates, Hydrocarbons Radionuclides	Windscreens and other enclosures Orientation of pile Slope of pile Foam covering and other coverings Dust suppressants
Grading	Particulates, Hydrocarbons Radionuclides	Light water sprays Surfactants
Stabilization/ Solidification	Particulates, Hydrocarbons	Enclosure of mixing area/apparatus Storage pile controls for raw materials Enclosure of binder preparation area Suction hood (in-situ treatment)

Source: EPA-450/1-89-001 - January 1989

SECTION 2

PROPOSAL TO IDENTIFY THE RISK FOR OFF-SITE MIGRATION OF WINDBLOWN ORGANIC, INORGANIC, AND/OR RADIOACTIVE CONTAMINANTS

PPCD - SECTION 2

1.0 INTRODUCTION

The following proposal outlines a suitable methodology to perform screening-level assessments of risk or screening-level impact analyses associated with contaminated sites during premitigation, active mitigation processes, or postmitigation. It is based on conservative principles and utilizes worst-case scenarios in order to maximize the predicted risk. The results of the assessment will be used to provide a basis for the evaluation of effectiveness of the clean-up technology and of proposed mitigation techniques from the standpoint of effectively reducing concentrations of contaminants at off-site receptors to levels which are deemed acceptable. It is important to note that this screening-level impact analysis should not be confused with the more detailed Baseline Risk Assessment which will be performed for each Operable Unit (OU). That assessment will make use of more detailed information on toxicity and exposure, quantify the integrated risk from all exposure pathways, consider uncertainty, and provide a risk to exposed members of the population, as well as an environmental risk. A plan for the evaluation of human health risk and environmental risks will be submitted as a separate task in accordance with the ER IAG.

The methodology essential to the identification or characterization of risk for off-site migration of windblown organic, inorganic and/or radioactive contaminants involves the principles described below. Assumptions and judgements are required at many levels throughout the analysis and these will be considered by technically competent individuals, with guidance from regulatory agencies.

Because fugitive emissions that could be generate by environmental restoration activities are not usually emitted from a definable point, such as a stack, they cannot be easily measured by conventional techniques. However, because they are emitted at or near ground level, fugitive emissions have a proportionally higher potential for near term adverse effects from windblown contaminant dispersion than do stack emissions. The impact of fugitive emissions is generally most critical on a short-term basis in the immediate vicinity of the source. Therefore, a monitoring strategy designed to evaluate average emissions at a limited number of specified locations in an existing area-wide monitoring network may not be sufficient to assure that hazardous emissions are controlled in the immediate vicinity of sources where area monitors may not exist. It is essential to address the short-term localized impact, as well as the long-term area-wide impact, in order to develop an adequate control strategy for fugitive emissions.

The short-term, localized impact of sources of fugitive emissions can be estimated both by dispersion modeling and by field measurement (upwind/downwind monitoring). There are advantages and disadvantages to both approaches. Monitoring is intuitively more attractive because it involves actual, measured data, while modeling is based on the mathematical simulation of assumed atmospheric processes. However, for monitoring to be reliable, the data collection program must be comprehensive in scope, subject to strict quality control, and must have adequate measurement sensitivity for the intended purpose. This is resource-intensive and not always feasible. Also, the interpretation of monitoring results is not always straightforward. Neighboring sources and/or high background concentrations often present complications. Even when it is possible to isolate the impact of the contaminant of concern, it is often difficult to relate this single result to an overall evaluation of contaminant dispersion. It may even prove difficult at some locations to adequately distinguish the impact of fugitive emissions from the target activities from that of other emissions or contaminants from other sources. Furthermore, monitoring cannot be used as a means to predict impacts of any proposed action such as potential impacts associated with the implementation of a remediation alternative.

Dispersion modeling, on the other hand, is relatively inexpensive and does not present the difficulties described above. The major disadvantage is the uncertainty associated with model estimates. The major sources of error in dispersion modeling include:

- Inadequacies in the simulation of physical phenomena by models;
- Inadequacies in the input data to models; and
- Lack of expertise in applying models and in interpreting the results.

These problem areas are more critical for fugitive emissions than for traditional stack sources because of the following complicating factors:

- Fugitive emission sources have generally ill-defined critical physical parameters necessary for modeling. Further, emission rates are often time-variable and frequently vary with the meteorological conditions (wind speed) under which they are being modeled.

- The release height of fugitive emission is generally near ground level, where diffusion patterns are often chaotic from disturbances associated with plant structures and work activities.

- The gravitational effects on larger particles may result in a non-uniform plume which is difficult to model. Detailed particle size data needed to address this problem are generally not available.

In addition, dispersion models are generally "conservative;" that is, the estimated impacts are higher than would actually be realized. However, this is desirable in the screening of potential risks, as long as the conservation is reasonable.

2.0 IDENTIFICATION OF RISK

2.1 Characterize Preremediation Sources or Potential Sources of Emissions for Subsequent Dispersion Model Use

Contaminated sites within the Rocky Flats facility have been characterized to some extent and grouped within OUs. The IAG contains information as to the contaminants present at each site. In addition, each OU and each IHSS within the OUs will be further characterized as a part of the RFI/RI process. The analysts will review the available literature/field studies performed for each IHSS or OU. It is proposed to visit each site to supplement data not available in the literature, and provide the analysts with sufficient feel for the task-at-hand.

The proposed methodology for characterization of the emissions sources will require a number of steps as outlined below. The analyst will collect the information in spreadsheet form in order to effectively manage the many informational requirements. All data will be given in Standard International (SI) units, with the exception of units of radiation activity, where units of Curies (Ci) are more suitable for direct comparison to existing standards. The proposed methodologies for characterization of emissions sources are presented below.

2.1.1 Identify Potential Sources of Air Contaminants

Potential air contaminant sources may include, but are not limited to contaminated landfills, impoundments, soil surfaces, structures (such as concrete pads with removable contamination), containers, and possibly storage tanks from which contaminants may volatilize. The windblown dust inventory (see Part II Section I) will be used as an essential resource in the completion of this task.

If, within the OU or the IHSS, one source is clearly dominant in terms of levels of contaminants and toxicity, it is proposed to concentrate on characterizing that particular source. This is believed to be a reasonable approach; however, caution will be applied to ensure that order that no important sources are overlooked.

2.1.2 Categorize Potential Emissions as Either Gaseous or Particulate Emissions

Gaseous emissions include volatile and semivolatile compounds. Particulate emissions include radionuclides, semivolatiles, base neutrals, metals and other organic compounds. Table 2-1 provides further guidance which will be used for classification of potential air contaminants. It is proposed to group

TABLE 2.1

POTENTIAL AIR CONTAMINANTS BY GENERIC
TYPE OF CONTAMINANT

Volatiles (>1 mm mercury vapor pressure)

- All monochlorinated solvents; also trichloroethylene, trichloroethane, tetrachlorethane
- Most simple aromatic solvents; benzene, xylene, toluene, ethylbenzene
- Some normal alkane; up to decane
- Inorganic gases; hydrogen sulfide, chlorine, sulfur dioxides

Semivolatiles (1-10^{-7} mm mercury vapor pressure)

- Most polychlorinated biphenyls; dichlorobenzenes, aroclors, dieldrin
- Most pesticides; aniline, toxaphene, nitroaniline, parathion, phthalates
- Most polynuclear aromatics; naphthalene, phenanthrene, benz(a)anthrencene

Non Volatiles or Particular Matter (<10^{-7} mm mercury vapor pressure)

- Larger polynuclear aromatics; chrysene, coronene
- Metals; lead, mercury, chromium
- Other inorganics; asbestos, arsenic, cyanides

Source: EPA-450/1-89-002
January 1989

each previously identified potential source of air contamination into its respective category.

2.1.3 Categorize Each Source as an Area, Volume or Line Source and Estimate its Dimensions

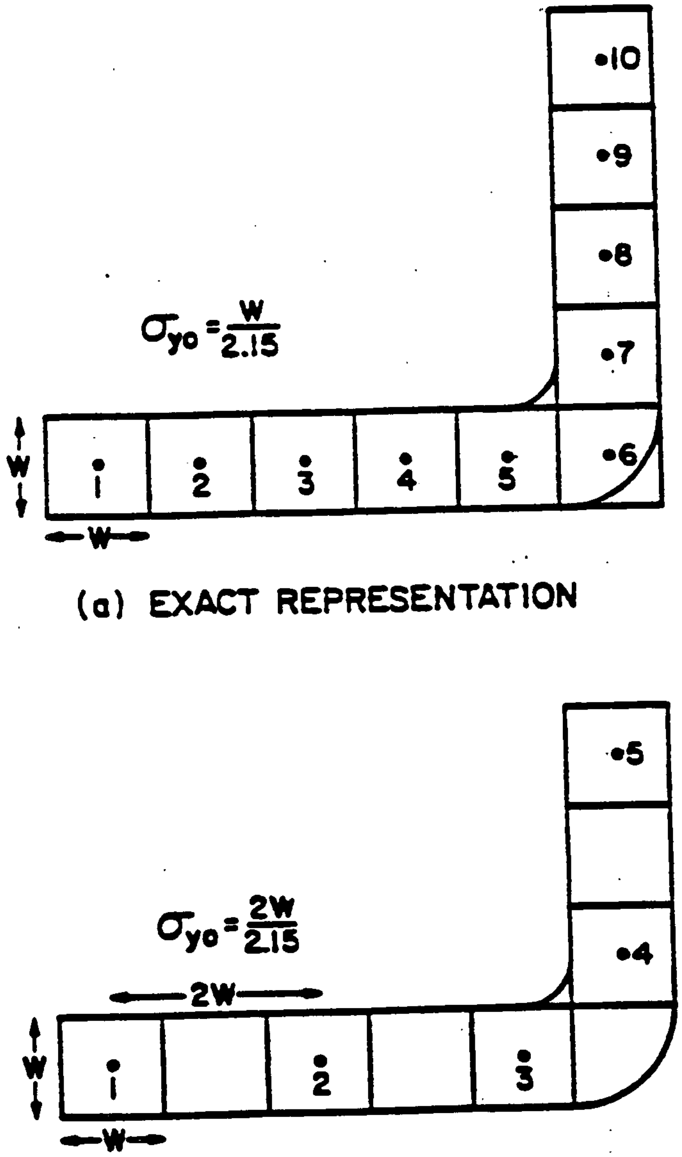
The majority of sources may be categorized as area sources. However, contaminated roadways are more accurately described as line sources. Tanks and containers may be considered as either volume or area sources.

A value for the length and width of the area source will be provided. For dispersion modeling purposes, each source must be square. Therefore, irregular shaped area sources will be characterized by fitting a group of appropriately sized squares to the irregular shape, as illustrated in Figure 2-1. Similarly, line sources will be characterized as multiple area or volume sources of equal length and width as depicted in Figure 2-2. For volume sources, the standard deviation of the vertical and crosswind source distribution is required.

2.1.4 Estimate the Number of Particulate Size Categories in the Particulate Distribution

This estimation will be used for air quality dispersion modeling to address the differences in behavior of particulates or droplets with significant gravitational settling velocities versus gaseous pollutants and small particulates which tend to be reflected from the surface. Larger particulates that come in contact with the surface may be completely or partially retained at the surface. The estimation of the number of particulate size categories in the particulate distribution will be made according to the requirements of the dispersion model.

FIGURE 2-1



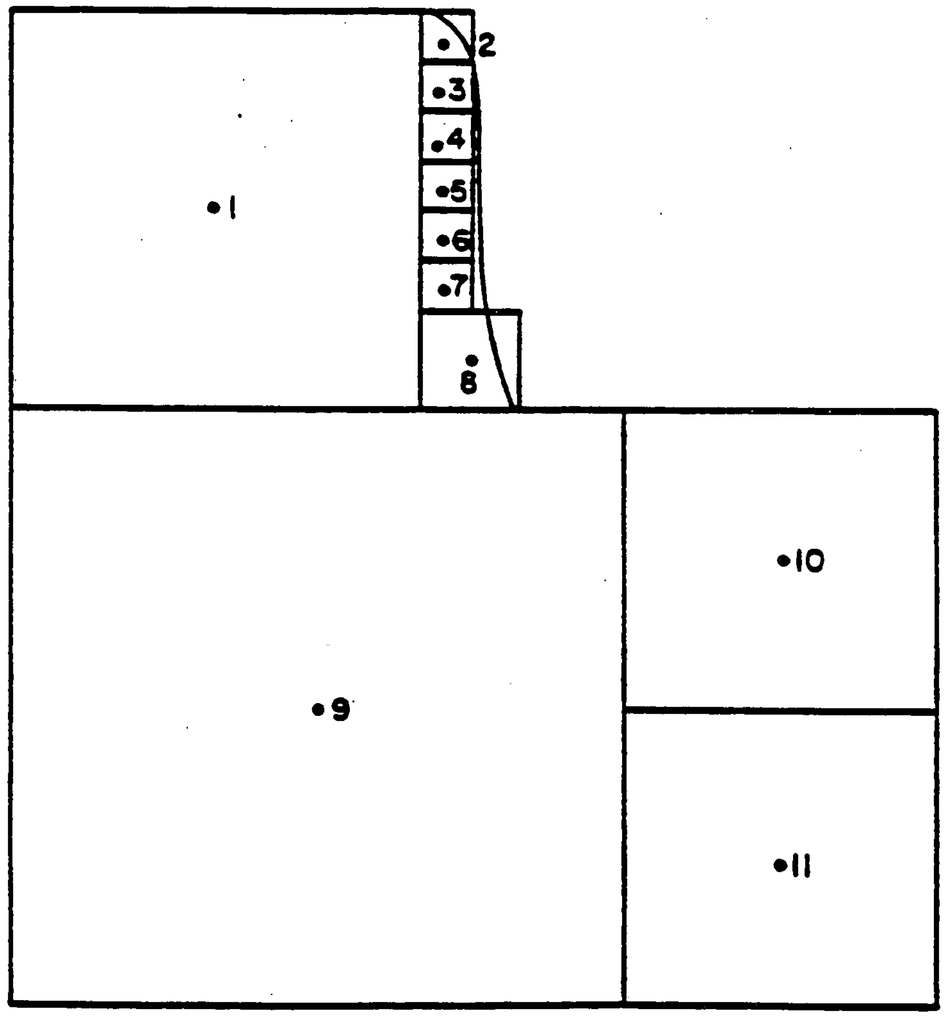
(a) EXACT REPRESENTATION

(b) APPROXIMATE REPRESENTATION

REPRESENTATION OF AN IRREGULARLY SHAPED AREA
BY 11 SQUARE AREA SOURCES

Source: EPA, 1987; 450/4-88-002a

FIGURE 2-2



EXACT AND APPROXIMATE REPRESENTATIONS OF A LINE SOURCE BY MULTIPLE VOLUME SOURCES

Source: EPA, 1987; 450/4-88-002a

Estimates will then be made of the settling velocity mass fraction, and surface reflection coefficients for each of the particle size categories. Calculations will be performed following the guidance given in EPA 1987b.

2.1.5 Estimate the Concentration of Each Contaminant Within Each Source

Estimates will be generated in ug/m^2 or Ci/m^2 for each contaminant. For contaminated soil surfaces the study will be confined to the uppermost layers of soil, or that layer which is likely to be suspended. The windblown dust inventory will be used as an essential resource to accomplish this task.

2.1.6 Define the Mechanisms Which May Lead to the Release of Air Contaminants from the Source

Mechanisms which may lead to the release of source contaminants into the air will be defined. For gas phase emissions, these mechanisms include volatilization and biodegradation. For particulate phase emissions, mechanisms include wind erosion and mechanical forces, such as truck traffic over contaminated road surfaces or tilling of contaminated fields. Table 2-2 provides a listing of the important air emission mechanisms applicable to each source. Mechanical resuspension is discussed in detail earlier in Part II.

TABLE 2.2 SOURCES ASSOCIATED WITH SUPERFUND ACTIVITIES AND THEIR CHARACTERISTICS

Superfund Source	Source Configuration[a]	Important Air Emission Mechanisms: Gas Phase	Important Air Emission Mechanisms: Particulate Phase	Emission Mode: Gas Phase	Emission Mode: Particulate Phase	Routine/ Non-Routine Release
Pre-remediation Sources:						
• Landfills	Fugitive Area	Volatilization, biodegradation	Wind Erosion, mechanical disturbances	Continuous	Intermittent	Routine
• Lagoons	Fugitive Area	Volatilization, biodegradation	Wind Erosion, mechanical disturbances	Continuous	Intermittent	Routine
• Contaminated soil surfaces	Fugitive Area	Volatilization, biodegradation	Wind Erosion mechanical disturbances	Continuous	Intermittent	Routine
• Containers	Fugitive Area volume	Volatilization, biodegradation	Mechanical diturbances	Continuous	Intermittent	Routine
• Process Facilities	Fugitive Area volume line, point	Volatilization, combustion	Wind Erosion, mechanical disturbances	Continuous	Intermittent	Routine
• Storage Tanks	Fugitive Area	Volatilization	--	Continuous	--	Routine
Remediation Sources:						
• Soil Handling	Fugitive Area, volume	Volatilization	Wind Erosion, mechanical disturbances	Continuous, Intermittent	Intermittent	Routine/ Non-Routine
• Air Stripper[b]	Point, Volume	Volatilization	Combustion	Continuous, Intermittent	Continuous	Routine/ Non-Routine
• Incinerator[b]	Point, Volume	Combustion	Combustion	Continuous, Intermittent	Continuous	Routine/ Non-Routine

(Continued)

TABLE 2.2 (Continued)

Superfund Source	Source[a] Configuration	Important Air Emission Mechanisms: Gas Phase	Important Air Emission Mechanisms: Particulate Phase	Emission Mode: Gas Phase	Emission Mode: Particulate Phase	Routine/ Non-Routine Release
Remediation Sources: (Continued)						
• In-situ Venting	Fugitive Area	Volatilization	--	Continuous Intermittent	--	Routine/ Non-Routine
• Solidification/ Stabilization	Fugitive Area, volume	Volatilization	Wind Erosion, mechanical disturbances	Continuous, Intermittent	Intermittent	Routine/ Non-Routine
Post-remediation Sources:						
• Landfills	Fugitive Area	Volatilization, biodegradation	Wind Erosion, mechanical disturbances	Continuous	Intermittent	Routine
• Lagoons	Fugitive Area	Volatilization, biodegradation	Wind Erosion, mechanical disturbances	Continuous	Intermittent	Routine
• Soil Surfaces	Fugitive Area	Volatilization, biodegradation	Wind Erosion, mechanical disturbances	Continuous	Intermittent	Routine
• Containers	Fugitive Area volume	Volatilization, biodegradation	Mechanical disturbances	Continuous	Intermittent	Routine

[a] Most Superfund sources are ground level or near ground level non-buoyant releases.

[b] Small stacks where plume is frequently in the downwash cavity.

Source: EPA-450/1-89-004
January 1989

2.1.7 Characterize the Temporal Distribution of Emissions

Distribution of emissions through time will be characterized. Emissions of gaseous compounds will be considered as continuous. Particulate emissions are intermittent. An estimation will be made of the period during which the defined air emission mechanisms will act on the source. As discussed previously, a conservative estimate will be provided.

2.1.8 Estimate the Long-Term, Average Emission Rate of Each Source

It is proposed that the applicable equations provided earlier be employed to estimate the average emissions associated with each source. For continuous emission, the emission rate in mass per unit time (g/sec) will be calculated for volume sources and mass per unit time per unit area ($g/s{\cdot}m^2$) for area sources. For intermittent emissions, the emission rate in g/sec will be calculated and the emission rate modified to account for the amount of time per year during which the air emissions mechanism is expected to act on the source.

2.1.9 Estimate Short-Term, Worst-Case Emissions

It is proposed that short-term, worst-case emissions be estimated in a manner similar to that described above. Continuous emissions will be equal to those calculated above for the long-term analysis. However, intermittent emissions may be significantly greater. To adequately evaluate intermittent emissions, it is proposed that a worst-case emissions scenario be constructed wherein all mechanical forces are acting at the same time (within the realm of physical possibility). The guidance provided in Part II Section 1.4 to estimate the maximum, short-term emissions rates will be utilized. It will be assumed that emissions can occur at this rate for at least a one-hour period, or if not feasible, the rate will be adjusted according to the appropriate timeframe.

2.1.10 Define a Coordinate System to Describe the Spatial Distribution of Sources, and Locate Each Source Within the Coordinate System

It is proposed that a Universal Transverse Mercator (UTM) coordinate system be used to identify the locations of all air emissions sources for modeling purposes. The UTM system provides the analyst with a consistent, definable reference coordinate system. It is also more flexible than a polar system for use in modeling to locate the point of maximum impact. UTM coordinates are read directly from USGS maps of the area. The 7 1/2 minute series is proposed.

It is then proposed to locate each source on the USGS maps. For area sources, the x and y coordinate of the southwest corner will define the source location. For volume sources, the x and y coordinate of the center of the source is proposed.

2.2 Select a Dispersion Model from the List of EPA-Recommended Models

It is proposed that a study to select an acceptable dispersion model for use at the RFP be undertaken. The guidance of the EPA Regional Meteorologist will be obtained as part of the evaluation in the selection of a model and a modeling approach. It is further proposed that guidance be obtained from the appropriate representative of the CDH.

2.3 Construct a Receptor Grid

It is proposed that a grid of receptor locations for input to the air quality dispersion model be constructed as a function of the selected dispersion model's requirements. The model selected must be capable of incorporating mondiscrete source term inputs, and vairable terrain features. The guidance of the EPA Regional Meteorologist will be obtained as part of the evaluation in the selection of a model and a modeling approach. It is further proposed that guidance be obtained from the appropriate representative of the CDH.

2.3.1 Locate the Site Boundary

The nearest site of public access is the site boundary and this is proposed as the nearest receptor location. Because each OU will consist of multiple sources, the distance to the boundary will be conservatively represented as the minimal straight-line distance between any source and the site boundary.

2.3.2 Construct a Receptor Grid Suitable to Assess Maximum Impacts

Appropriate distances from the boundary will then be selected for impact analysis with the goal of determining the off-site location of maximum impact. It should be noted that in the analysis of maximum, short-term impacts, the analysis can be simplified by assuming that impacts may occur in any direction. This is reasonable because each wind direction is likely to occur for at least one hour per year. Because the types of sources to be considered are, for the most part, nonbuoyant, distances to receptor locations should be rather small. For example, as a first cut, the analyst might select distances of 20 meters. The model will then calculate impacts at the nearest location of the site boundary and each 20 meters downwind to a distance of 500 meters. It is expected that within this grid of receptor points, the analyst will see that impacts have peaked, and thereafter decrease with increasing distance from the source. The analyst will perform additional iterations, with additional receptor locations located close to the peak impact location derived from the first model executions, in order to be assured that the peak impact and its location are not overlooked.

2.3.3 Construct a Receptor Grid Suitable to Assess Long-Term Impacts

It is proposed that the assessment of long-term impacts will utilize actual site meteorology in the form of a joint frequency distribution (JFD) of wind speed, wind direction and atmospheric stability class. Guidance for the construction of a JFD utilizing data from the on-site meteorological monitoring program is given in Appendix A. The JFD should be constructed for the lowest available sensor height. An anemometer height of 10 meters is typically used in the analysis of impact due to ground-level releases.

The analyst will calculate impacts in all directions from the source. As it is prohibitively expensive and unreasonable to construct a grid with the resolution used in the short-term assessment, the analyst will use judgement. It is proposed that the nearest source-boundary distance (such as the distance from the nearest edge of the tank, concrete pad, etc. to the site boundary) be used as the initial distance and additional receptors assigned at incremental distances of 20, 30, or even 50 meters to an applicable distance wherein impacts are shown to peak and thereafter decrease with increasing distance. The results of the short-term analysis will be used as guidance.

2.4 Assign Other Required Meteorological Parameters

Air dispersion models will require the following meteorological input parameters:

- ambient air temperature
- height of the top of the surface mixing layer

Example values for these parameters are shown in Table 2-3. The analyst will utilize the appropriate value corresponding to the time period under consideration.

2.5 Define Worst-Case Meteorological Conditions and Utilize EPA-Recommended Screening-Level Air Dispersion Models to Predict Maximum Short-Term Downwind Concentrations of Contaminants at Off-Site Receptors

Each source will impart maximum downwind impacts with a unique set of meteorological conditions. Similarly, the multiple sources which comprise an OU will impart maximum impacts with a unique set of meteorological conditions. A means to "predict" the worst-case short-term meteorology commonly used involves the use of an air quality dispersion model. An additional study is proposed to select a suitable air dispersion model for the RFP.

Models require input data as described in Section 2.4 (i.e., emissions source characterization, receptor grid, etc.), as well as one-hour meteorological data. Generally, one wind direction must be selected for modeling purposes. (Note that receptor location selection, as described above, must be in the

TABLE 2.3

Wind Speed and Stability Class Combinations
Used by a Representative Model

Stability Class	10-m Wind Speed (m/s)								
	1	2	3	4	5	8	10	15	20
A	*	*	*						
B	*	*	*	*	*				
C	*	*	*	*	*	*	*		
D	*	*	*	*	*	*	*	*	*
E	*	*	*	*	*				
F (rural only)	*	*	*	*					

Source: EPA-450/1-88-010
January 1988

downwind direction. For instance, if the wind direction assigned is west, downwind receptors should be considered east of the source.) The assignment of meteorological scenarios will include an array of wind speeds and atmospheric stability classes. Models allow many user switches/options. The regulatory default options will always be chosen, unless the Regional Meteorologist or CDH representative dictate that others are more suitable. All input parameters will be carefully evaluated, and an input file will be constructed as required by the model. The test case will be constructed and run with the model software to ascertain that the model is functioning properly. The model may be run to calculate impacts from each of the single sources of the OU. Predicated downwind impacts will then be added (by assuming they will all maximally impact at the same location) to predict a worst-case, one-hour impact. Alternatively, if multiple sources are to be analyzed, they may be collocated (assumed to be emanating from the same location) which will tend to maximize impacts.

If impacts, predicted in this manner, are below levels deemed acceptable, no further analysis will be required. If not, the modeling technique will be refined. Placing each source at its actual source location and utilizing each wind direction with each of the 32 meteorological scenarios will provide a more accurate estimate. If impacts are still unacceptable the analyst will investigate the use of further mitigation (such as additional watering, lower traffic speed, etc.) in order to lessen emissions, and will provide guidance as to means by which impacts may be reduced, such as by not allowing mitigation to occur during the meteorological episodes or periods which contribute to maximum impacts. For instance, if it is shown through the modeling analysis that maximum impacts of soils rarely occur during periods with wind speeds less than 20 mph, then such activities should be restricted to less windy periods.

2.6 Utilize EPA-Recommended Screening Level Air Dispersion Models to Predict Maximum Long-Term Downwind Concentrations of Contaminants at Off-Site Receptors

The analyses of long-term impacts will require the use of a joint frequency distribution (JFD) of wind speed, wind direction and atmospheric stability class. It is proposed to follow EPA's recommendation that analyses of annual impacts be conducted utilizing five individual years of JFDs. Guidance to be followed for the construction of a JFD utilizing data from the on-site meteorological monitoring program is included in Appendix A. It is further proposed that JFDs be constructed to relate to the time period for which short-term (at least one month) remedial options are to be conducted. For instance, if soils handling is to be conducted during the summer months, a JFD will be constructed for each of the available summer periods (1985 through 1989) and analyses conducted with each of these meteorological data sets.

2.7 Evaluate Maximum Predicted Downwind Concentrations Against an Acceptable Risk Criteria

The policy statement defines certain limits or criteria which, with regulatory concurrence, will be considered acceptable for use in the screening-level assessment. That is, if predicted downwind concentrations at the point of maximum impact do not exceed these criteria, the implementation procedure as planned is acceptable and no further mitigation is required. If the levels are not acceptable, additional mitigation techniques to further reduce potential emissions will be applied or, alternatively, guidance for the performance of more detailed risk assessments will be followed.

APPENDIX A

1. Proposal for the Construction of a Joint Frequency Distribution of Wind Speed, Wind Direction, and Atmospheric Stability Class

2. Tables A-4, A-5, and A-6 of Wind Direction Frequency at the Rocky Flats Plant: 1986 - 1988

3. Summary Wind Rose for the Rocky Flats Plant: 1987 - 1989

PROPOSAL FOR THE CONSTRUCTION OF A JOINT FREQUENCY DISTRIBUTION OF WIND SPEED, WIND DIRECTION AND ATMOSPHERIC STABILITY CLASS

The EPA recommends that the following principles be used in the construction of a joint frequency distribution (JFD) of wind speed, wind direction and atmospheric stability class for use in air quality impacts modeling. These recommendations have been extracted from EPA's Guideline on Air Quality Models (Revised 1986), and it is proposed that they be followed at the RFP to generate meteorological data that will be used to support environmental restoration activities.

1. General Guidance

It is proposed that guidance provided in the "Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD)" (EPA 1980) be used for the establishment of special monitoring networks for PSD and other air quality modeling analyses. Site-specific data for model applications will cover as long a period of measurement as is possible to ensure adequate representation of "worst-case" meteorology. It is proposed that measurement locations will be submitted to the EPA Regional Office for approval of appropriateness.

All site-specific data will be reduced to hourly averages. Table A-1 lists the wind related parameters and the averaging time requirements.

Table A-1

Averaging Times for Site-Specific Wind and Turbulence Measurements

Parameter	Averaging Time
Surface wind speed (for use in stability determinations)	1-hr
Transport direction	1-hr
Dilution wind speed	1-hr
Turbulence measurements (σ_E and σ_A) for use in stability determinations	1-hr*

*To minimize meander effects in σ_A when wind conditions are light and/or variable, determine the hourly average σ from four 15-minute σ's according to the following formula:

$$\sigma_{1-hr} = \sqrt{\frac{\sigma_{15}^2 + \sigma_{15}^2 + \sigma_{15}^2 + \sigma_{15}^2}{4}}$$

Source: EPA-450/2-78-027R
1986

2. Assignment of Hourly Values for Stability Class

It is proposed that the Pasquill-Gifford (P-G) method be used to derive stability categories. The P-G stability categories couple near-surface measurements of wind speed with subjectively determined insolation assessments based on hourly cloud cover and ceiling observations. The method specifies wind speed measurements made at or near 10 m above ground. The insolation rate is typically assessed using the cloud cover and ceiling height data as available from a nearby first order National Weather Service (NWS) Station. Because these data are not readily available, and data collected at the NWS Station at Denver are not expected to be characteristic of conditions at Rocky Flats, an alternative approach is required. In the absence of such observations, it is proposed that the P-G stability category be estimated using Table A-2. This table requires E, the standard deviation of the vertical wind direction fluctuations. If the surface roughness of the area surrounding the source is different from the 15 cm roughness length upon which the table is based, an adjustment may be made as indicated in the second footnote of Table A-2. E is computed from direct measurements of the elevation angle of the vertical wind directions.

If measurements of elevation angle are not available, $_E$ may be determined using the transform:

$$\sigma_E = \sigma_w/u.$$

where: σ_E = the standard deviation of the vertical wind direction fluctuations over a one-hour period.

Table A- 2

Wind Fluctuation Criteria For Estimating Pasquill Stability Categories*

Pasquill Stability Category	Standard Deviation of the Horizontal Wind Direction Fluctuations**, *** (σ_A in degrees)	Standard Deviation of the Vertical Wind Direction Fluctuations**, **** (σ_E in degrees)
A	$\sigma_A \geq 22.5°$	$\sigma_E \geq 11.5°$
B	$17.5° \leq \sigma_A < 22.5°$	$10.0° \leq \sigma_E < 11.5°$
C	$12.5° \leq \sigma_A < 17.5°$	$7.8° \leq \sigma_E < 10.0°$
D	$7.5° \leq \sigma_A < 12.5°$	$5.0° \leq \sigma_E < 7.8°$
E	$3.8° \leq \sigma_A < 7.5°$	$2.4° \leq \sigma_E < 5.0°$
F	$\sigma_A < 3.8°$	$\sigma_E < 2.4°$

Adapted from: Irwin, J., 1980.

*These criteria are appropriate for steady-state conditions, a measurement height of 10 m, for level terrain, and an aerodynamic surface roughness length of 15 cm. Care should be taken that the wind sensor is responsive enough for use in measuring wind direction fluctuations.(See EPA 1980).

**A surface roughness factor of $(z_0/15 \text{ cm})^{0.2}$, where z_0 is the average surface roughness in centimeters within a radius of 1-3 km of the source, may be applied to the table values. It should be noted that this factor, while theoretically sound, has not been subjected to rigorous testing and may not improve the estimates in all circumstances. A table of z_0 values that may be used as a guide to estimating surface roughness is given in Smedman-Hogstrom and Hogstrom (1978).

***These criteria are from a NRC proposal. It would seem reasonable to restrict the possible categories to A through D during daytime hours with a restriction that for 10-m wind speeds above 6 m/s, conditions are neutral. Likewise, during the nighttime hours, some restrictions, as in Table 9-3, are needed to preclude occurrences of categories A through C.(NRC 1972).

****These criteria were adapted from those presented by Smith and Howard (1972). It would seem reasonable to restrict the possible categories to A through D during the daytime hours and to categories D through F during the night-time hours. During the daytime, conditions are neutral for 10-m wind speeds equal to or greater than 6 m/s, and during the night, conditions are neutral for 10-m wind speeds equal to or greater than 5 m/s.

Source: EPA-450/2-78-027R
1986

σ_w = the standard deviation of the vertical wind speed fluctuations over a one-hour period.

u = the average horizontal wind speed for a one-hour period.

Since both σ_w and u are in meters per second, σ_E is in radians. To use σ_E in Table A-2, σ_E will be converted to degrees. It is proposed that a vertically mounted propeller anemometer be used to measure the vertical wind speed fluctuations. The instrument should meet the specifications given in the Ambient Monitoring Guidelines referenced above. σ_w will be computed directly each hour using at least 360 values based on a recommended readout interval of up to 10 seconds. If σ_E is computed using the output of the anemometer by other than direct application of the formula for a variance, the method will be demonstrated to be equivalent to direct computation. Both the vertical wind speed fluctuations and the horizontal wind speed should be measured at the same level. Moreover, it is proposed that measurements be made at a height of 10 m for use in estimating the P-G stability category. Where trees or land use preclude measurements as low as 10 m, measurements should be made at a height above the obstructions.

If on-site measurements of either σ_E or σ_w are not available, stability categories will be determined using the horizontal wind direction fluctuation, σ_A, as outlined by Irwin (1980). Irwin includes the Mitchell and Timbre (1979) method that uses categories of σ_A (NRC 1972) listed in Table A-3, as an initial estimate of the P-G stability category. This relationship is considered adequate for daytime use. During the nighttime (one hour prior to sunset to one hour

Table A-3

Nighttime* P-G Stability Categories Based on σ_A

If the σ_A Stability Category is	And the Wind Speed at 10 m is m/s	Then the Pasquill Stability Category is
A	<2.9	F
	2.9 to 3.6	E
	$\geq$3.6	D
B	<2.4	F
	2.4 to 3.0	E
	$\geq$3.0	D
C	<2.4	E
	$\geq$2.4	D
D	wind speed not considered	D
E	wind speed not considered**	E
F	wind speed not considered***	F

Adapted from Irwin, J. 1980[68].

*Nighttime is considered to be from 1 hour prior to sunset to 1 hour after sunrise.

**The original Mitchell and Timbre (1979) table had no wind speed restrictions; However, the original Pasquill criteria suggest that for wind speeds greater than 5 m/s, neutral conditions should be used.

***The original Mitchell and Timbre (1979) table had no wind speed restrictions; however, the original Pasquill criteria suggest that for wind speeds greater than or equal to 5 m/s, the D category would be appropriate, and for wind speeds between 3 m/s and 5 m/s, the E category should be used.

after sunrise), the adjustments given in Table A-3 will be applied to these categories. As with σ_E an hourly average σ_A will be adjusted for surface roughness by multiplying the table values of σ_A by a factor based on the average surface roughness length determined within 1 to 3 km of the source. The need for such adjustments will be determined on a case-by-case basis.

Wind direction meander may, at times, lead to an erroneous determination of P-G stability category based on σ_A. To minimize wind direction meander contributions, σ_A will be determined for each of four 15-minute periods in an hour. However, 360 samples are needed during each 15-minute period. To obtain the σ_A for stability determinations in these situations, the square root of one-quarter of the sum of the squares of the four 15-minute σ_A's, as illustrated in the footnote to Table A-1 will be taken. While this approach is acceptable for determining stability, σ_A's calculated in this manner are not likely to be suitable for input to models under development that are designed to accept on-site hourly σ's based on 60-minute periods.

There has not been a widespread use of σ_E and σ_A to determine P-G categories. As mentioned in the footnotes to Table A-2, the techniques outlined have not been extensively tested. The criteria listed in Table A-2, are for σ_E and σ_A values at 10 m. For best results, the σ_E and σ_A values should be for heights near the surface as close to 10 m as practicable. Obstacles and large roughness elements may preclude measurements as low as 10 m. If circumstances preclude measurements below 30 m, the Regional Meteorologist will be consulted to determine the appropriate measurements to be taken on a case-by-case basis. The criteria listed in Tables A-2 and A-3 result from studies conducted in relatively flat terrain in rather ideal circumstances. For routine applications where conditions are often less than ideal, it is proposed that a temporary program be initiated at each site to spot-check the stability class estimates. Irwin's method using σ_E or σ_A will be compared with P-G stability class estimates using on-site wind speed and subjective assessments of the insolation based on ceiling height and cloud cover. The Regional Meteorologist will be consulted when using the spot-check results to refine and adjust the preliminary criteria outlined in Tables A-2 and A-3.

In summary, it is proposed that when on-site data sets are being used, Pasquill-Gifford stability categories be determined from one of the following schemes listed in the order of preference:

(1) The use of site-specific data which include cloud cover, ceiling height and surface (approximately 10 m) wind speeds.

(2) σ_E from site-specific measurements and Table B-2 (σ_E may be determined from elevation angle measurements or may be estimated from measurements of σ_W according to the transform: $\sigma_E = \sigma_w/u$ (as discussed above).

(3) σ_A from site-specific measurements and Tables A-2 and A-3.

(4) The use of site-specific wind speed with cloud cover and ceiling height from a nearby NWS site.

3. Use of Stability Arrays Software Package

A software program will be required to sort the hourly average data and develop the JFD in the format required for model input. The National Climatic Data Center has a program to develop the JFD, commonly called Stability Array, or STAR deck. It is proposed to modify this to accept the data inputs from the Rocky Flats Site. Optionally, an original software program could be coded to accept the Rocky Flats meteorological data and develop the required arrays.

WIND DIRECTION FREQUENCY
AT THE ROCKY FLATS PLANT
1986 - 1988

TABLE A-4 Wind Direction Frequency (Percent), by Four Wind-Speed Classes, at the Rocky Flats Plant

(Fifteen-Minute Averages–1986)[a]

	Calm	1-3 (m/s)[b]	3-7 (m/s)	7-15 (m/s)	>15 (m/s)	TOTAL
-	7.01	-	-	-	-	7.01
N	-	2.50	2.88	0.33	0.00	5.71
NNE	-	2.78	2.61	0.25	0.00	5.64
NE	-	2.54	1.32	0.09	0.00	3.95
ENE	-	2.06	0.53	0.01	0.00	2.60
E	-	2.33	0.42	0.00	0.00	2.75
ESE	-	2.22	1.00	0.00	0.00	3.22
SE	-	2.71	1.78	0.02	0.00	4.51
SSE	-	2.80	2.50	0.08	0.00	5.38
S	-	2.74	2.59	0.17	0.00	5.50
SSW	-	2.25	2.17	0.21	0.00	4.63
SW	-	2.68	2.49	0.25	0.00	5.42
WSW	-	3.12	4.06	0.88	0.04	8.10
W	-	3.50	2.85	1.97	0.79	9.11
WNW	-	3.64	3.52	3.88	0.54	11.58
NW	-	3.41	3.80	1.09	0.03	8.33
NNW	-	2.79	3.44	0.33	0.00	6.56
TOTALS	7.01	44.07	37.96	9.56	1.40	100.00

a. Data obtained from sensors located approximately 10 m (33 ft) above the ground.

b. For conversion purposes, miles per hour (mph) equals 2.237 multiplied by meters per second (m/s).

Source: Rocky Flats Plant Site Environmental Report for 1986, RFP-ENV-86

FIGURE A-1 1986 Annual Wind Rose for the Rocky Flats Plant

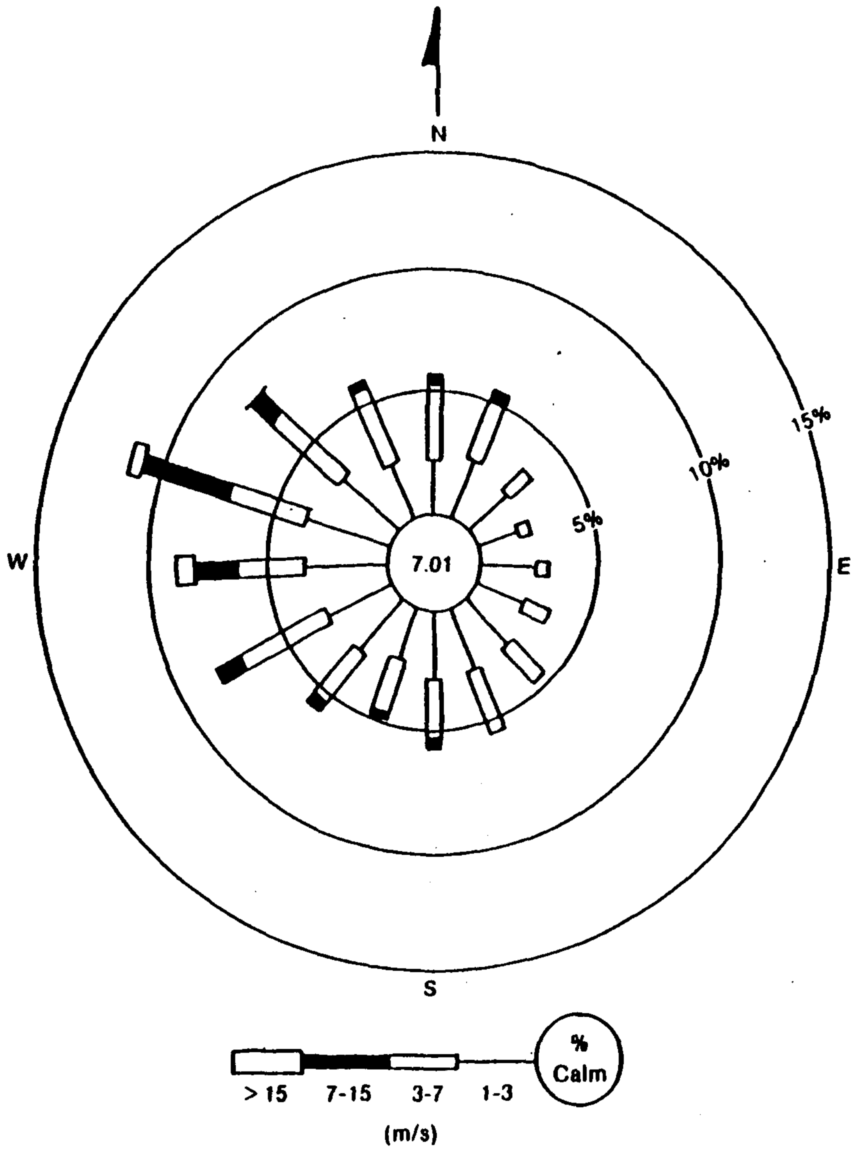


TABLE A-5 Wind Direction Frequency (Percent), by Four Wind-Speed Classes, at the Rocky Flats Plant[a]

(Fifteen-Minute Averages–1987[b])

	Calm	1-3 (m/s)[c]	3-7 (m/s)	7-15 (m/s)	>15 (m/s)	TOTAL
-	8.11	-	-	-	-	8.11
N	-	2.71	3.61	0.50	0.01	6.82
NNE	-	2.55	1.97	0.19	0.00	4.72
NE	-	1.84	0.75	0.02	0.00	2.62
ENE	-	1.44	0.26	0.00	0.00	1.70
E	-	1.99	0.20	0.01	0.00	2.19
ESE	-	1.91	0.83	0.01	0.00	2.75
SE	-	2.62	1.72	0.02	0.00	4.37
SSE	-	2.49	2.02	0.13	0.00	4.64
S	-	2.52	2.63	0.19	0.00	5.34
SSW	-	3.05	3.00	0.19	0.00	6.25
SW	-	3.43	3.32	0.12	0.00	6.86
WSW	-	3.74	4.85	0.35	0.00	8.94
W	-	4.31	2.95	0.96	0.15	8.38
WNW	-	3.67	3.65	3.19	0.38	10.89
NW	-	3.17	3.77	1.41	0.01	8.37
NNW	-	2.82	3.66	0.24	0.00	6.72
TOTALS	8.11	44.26	39.20	7.54	0.56	100.00

a. May data taken from 1986 due to data recording failure in May 1987.
b. Data obtained from sensors located 10 m (33 ft) above the ground.
c. For conversion purposes, miles per hour (mph) equals 2.237 multiplied by meters per second (m/s).

Source: Rocky Flats Plant Site Environmental

FIGURE A2 1987 Annual Wind Rose for the Rocky Flats Plant

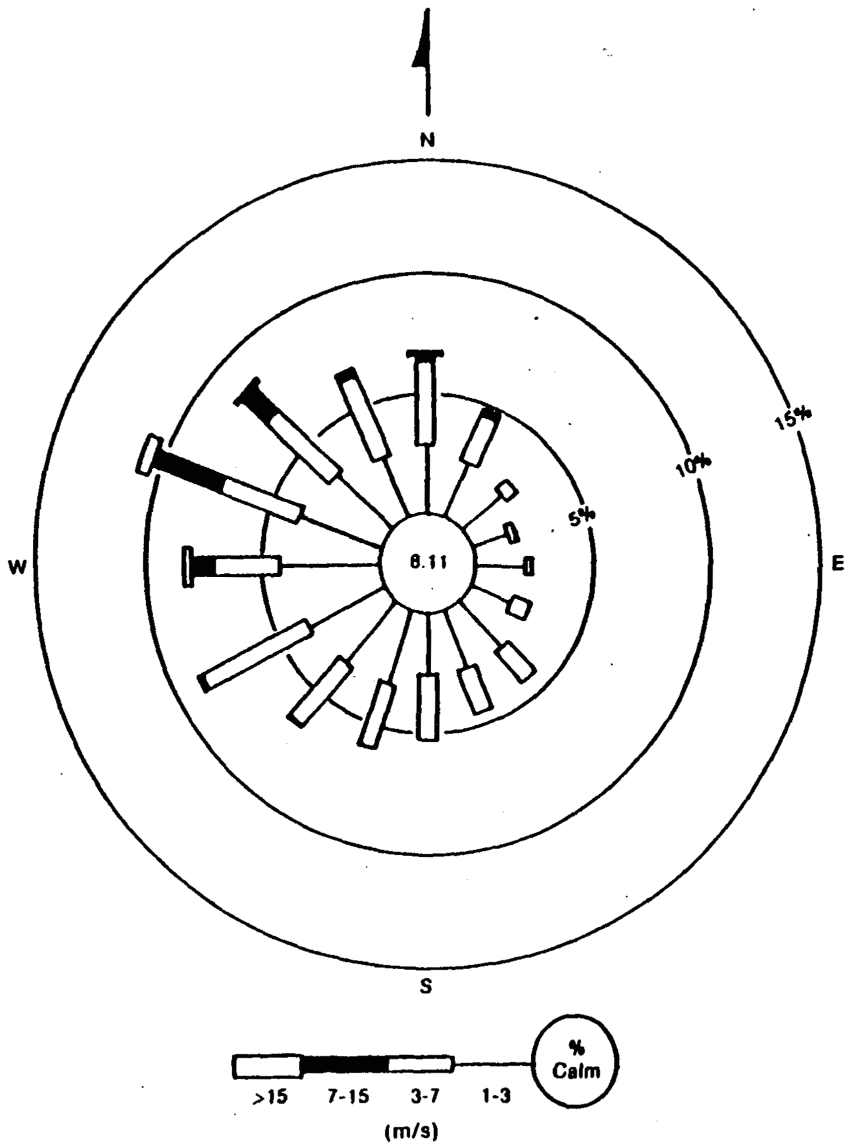


Table A-6 Wind Direction Frequency (Percent), by Four Wind-Speed Classes, at the Rocky Flats Plant

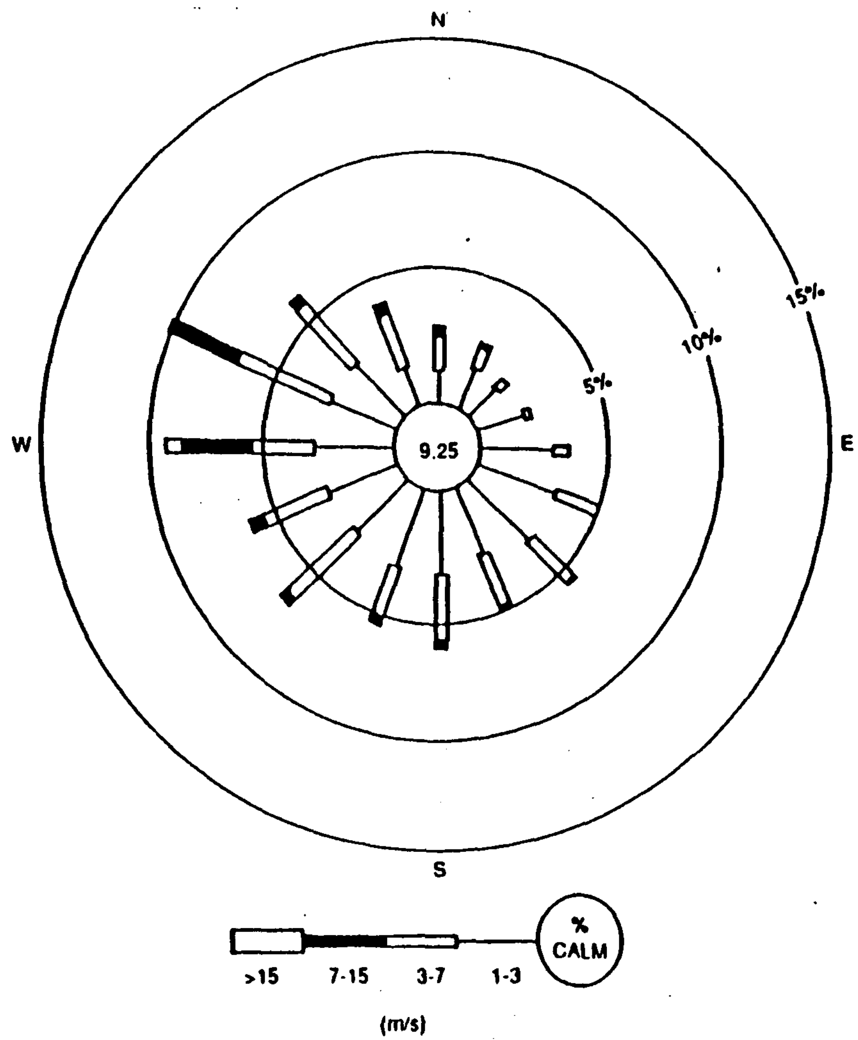
(Fifteen-Minute Averages — 1988)

Wind Direction	Calm	1-3 (m/s)	3-7 (m/s)	7-15 (m/s)	>15 (m/s)	TOTAL
-	9.25	-	-	-	-	9.25
N	-	1.25	1.57	0.55	0.00	3.37
NNE	-	1.94	1.10	0.13	0.00	3.17
NE	-	1.80	0.47	0.00	0.00	2.27
ENE	-	2.09	0.13	0.01	0.00	2.23
E	-	3.07	0.61	0,01	0.00	3.69
ESE	-	3.46	1.81	0.07	0.00	5.34
SE	-	3.55	2.37	0.21	0.00	6.13
SSE	-	2.92	2.46	0.27	0.00	5.65
S	-	3.44	2.79	0.34	0.00	6.57
SSW	-	3.37	2.35	0.30	0.00	6.02
SW	-	2.97	3.98	0,49	0.00	7.44
WSW	-	3.06	3.06	0.71	0.04	6.87
W	-	3.39	2.87	2.96	0.72	9.94
WNW	-	3.03	4.42	2.79	0.12	10.36
NW	-	3.13	3.44	0.59	0.00	7.16
NNW	-	1.77	2.32	0.45	0.00	4.54
TOTAL	9.25	44.24	35.75	9.88	0.88	100.00

Source: Rocky Flats Plant Site Environmental Report for 1988 RFP-ENV-88

FIGURE A3 1988 Annual Wind Rose for the Rocky Flats Plant

8



Summary Wind Rose for the Rocky Flats Plant

1987-1989

Compiled by

Michael L. Smith
Emergency Assessment Systems Branch
Safeguards & Security Department

EG&G Rocky Flats, Inc.

June 26, 1990

WINDROSE1_8789 run on 26-JUN-90 at 09:13:47 for RFP for the years 1987-89.
105216 records were read from the file.
85847 records (81.6%) were included in the Joint Frequency Function matrices.
19369 records (18.4%) had missing data and were excluded from the matrices.

ALL STABILITY CLASSES

knts:	0.0-4.0	4.0-7.0	7.0-11.0	11.0-17.0	17.0-21.0	>=21.0	TOTALS
N	0.0108	0.0182	0.0224	0.0163	0.0046	0.0022	0.0746
NNE	0.0101	0.0145	0.0161	0.0088	0.0020	0.0016	0.0531
NE	0.0087	0.0123	0.0103	0.0032	0.0003	0.0001	0.0350
ENE	0.0069	0.0096	0.0082	0.0017	0.0002	0.0001	0.0266
E	0.0063	0.0084	0.0070	0.0014	0.0000	0.0000	0.0233
ESE	0.0053	0.0100	0.0093	0.0025	0.0002	0.0000	0.0274
SE	0.0065	0.0137	0.0135	0.0049	0.0003	0.0000	0.0389
SSE	0.0075	0.0154	0.0185	0.0100	0.0012	0.0003	0.0529
S	0.0084	0.0162	0.0196	0.0119	0.0014	0.0005	0.0581
SSW	0.0095	0.0157	0.0183	0.0087	0.0010	0.0006	0.0538
SW	0.0091	0.0171	0.0229	0.0097	0.0013	0.0005	0.0606
WSW	0.0096	0.0193	0.0296	0.0189	0.0032	0.0025	0.0832
W	0.0121	0.0223	0.0233	0.0177	0.0079	0.0119	0.0952
WNW	0.0125	0.0226	0.0254	0.0287	0.0172	0.0287	0.1351
NW	0.0118	0.0224	0.0277	0.0217	0.0079	0.0086	0.1001
NNW	0.0111	0.0195	0.0269	0.0189	0.0041	0.0016	0.0822
TOTALS	0.1464	0.2573	0.2990	0.1852	0.0528	0.0593	1.0000

WINDROSE1_8789 run on 26-JUN-90 at 09:13:47 for RFP for the years 1987-89.
105216 records were read from the file.
85847 records (81.6%) were included in the Joint Frequency Function matrices.
19369 records (18.4%) had missing data and were excluded from the matrices.

STABILITY CLASS G

knts:	0.0-4.0	4.0-7.0	7.0-11.0	11.0-17.0	17.0-21.0	>=21.0	TOTALS
N	0.0009	0.0012	0.0012	0.0018	0.0012	0.0006	0.0069
NNE	0.0007	0.0007	0.0009	0.0012	0.0007	0.0009	0.0051
NE	0.0005	0.0006	0.0004	0.0002	0.0000	0.0000	0.0017
ENE	0.0002	0.0002	0.0002	0.0000	0.0000	0.0000	0.0006
E	0.0001	0.0004	0.0003	0.0000	0.0000	0.0000	0.0007
ESE	0.0000	0.0001	0.0003	0.0002	0.0000	0.0000	0.0006
SE	0.0001	0.0000	0.0003	0.0001	0.0000	0.0000	0.0006
SSE	0.0002	0.0003	0.0009	0.0009	0.0003	0.0001	0.0027
S	0.0003	0.0010	0.0016	0.0021	0.0002	0.0002	0.0054
SSW	0.0004	0.0012	0.0022	0.0016	0.0002	0.0001	0.0056
SW	0.0004	0.0016	0.0038	0.0020	0.0001	0.0000	0.0080
WSW	0.0004	0.0020	0.0068	0.0060	0.0004	0.0003	0.0158
W	0.0005	0.0014	0.0025	0.0014	0.0009	0.0021	0.0088
WNW	0.0005	0.0013	0.0017	0.0023	0.0020	0.0027	0.0104
NW	0.0005	0.0017	0.0027	0.0026	0.0008	0.0008	0.0092
NNW	0.0006	0.0016	0.0024	0.0027	0.0012	0.0003	0.0088
TOTALS	0.0065	0.0152	0.0280	0.0251	0.0080	0.0081	0.0909

WINDROSE1_8789 run on 26-JUN-90 at 09:13:47 for RFP for the years 1987-89.
105216 records were read from the file.
85847 records (81.6%) were included in the Joint Frequency Function matrices.
19369 records (18.4%) had missing data and were excluded from the matrices.

STABILITY CLASS F

knts:	0.0-4.0	4.0-7.0	7.0-11.0	11.0-17.0	17.0-21.0	>=21.0	TOTALS
N	0.0007	0.0008	0.0015	0.0019	0.0007	0.0003	0.0059
NNE	0.0010	0.0009	0.0017	0.0017	0.0004	0.0003	0.0061
NE	0.0008	0.0008	0.0009	0.0003	0.0001	0.0000	0.0029
ENE	0.0004	0.0004	0.0006	0.0001	0.0000	0.0000	0.0015
E	0.0001	0.0003	0.0005	0.0001	0.0000	0.0000	0.0011
ESE	0.0002	0.0002	0.0007	0.0002	0.0000	0.0000	0.0013
SE	0.0002	0.0003	0.0007	0.0004	0.0000	0.0000	0.0016
SSE	0.0004	0.0008	0.0015	0.0014	0.0001	0.0000	0.0042
S	0.0006	0.0013	0.0029	0.0021	0.0003	0.0001	0.0072
SSW	0.0005	0.0015	0.0030	0.0018	0.0002	0.0000	0.0072
SW	0.0007	0.0020	0.0044	0.0018	0.0002	0.0000	0.0091
WSW	0.0007	0.0030	0.0066	0.0037	0.0005	0.0006	0.0150
W	0.0009	0.0024	0.0028	0.0022	0.0010	0.0018	0.0111
WNW	0.0008	0.0025	0.0035	0.0035	0.0022	0.0036	0.0161
NW	0.0009	0.0030	0.0044	0.0032	0.0012	0.0010	0.0136
NNW	0.0008	0.0019	0.0040	0.0037	0.0007	0.0003	0.0114
TOTALS	0.0097	0.0221	0.0398	0.0280	0.0077	0.0081	0.1154

W[redacted]NDROSE1_8789 run on 26-JUN-90 at 09:13:47 for RFP for the years 1987-89.
105216 records were read from the file.
[redacted]847 records (81.6%) were included in the Joint Frequency Function matrices.
[redacted]369 records (18.4%) had missing data and were excluded from the matrices.

STABILITY CLASS E

knts:	0.0-4.0	4.0-7.0	7.0-11.0	11.0-17.0	17.0-21.0	>=21.0	TOTALS
N	0.0006	0.0017	0.0027	0.0019	0.0003	0.0003	0.0075
N[redacted]E	0.0019	0.0025	0.0044	0.0029	0.0004	0.0003	0.0125
NE	0.0016	0.0019	0.0022	0.0010	0.0001	0.0000	0.0067
E[redacted]E	0.0010	0.0014	0.0016	0.0004	0.0000	0.0000	0.0044
[redacted]	0.0007	0.0010	0.0013	0.0004	0.0000	0.0000	0.0034
E[redacted]E	0.0004	0.0010	0.0017	0.0006	0.0000	0.0000	0.0036
S[redacted]	0.0007	0.0016	0.0026	0.0013	0.0001	0.0000	0.0063
SSE	0.0011	0.0027	0.0046	0.0032	0.0004	0.0002	0.0122
[redacted]	0.0012	0.0040	0.0063	0.0042	0.0007	0.0001	0.0164
SSW	0.0016	0.0039	0.0056	0.0026	0.0003	0.0002	0.0141
S[redacted]	0.0018	0.0047	0.0066	0.0027	0.0003	0.0002	0.0162
W[redacted]W	0.0016	0.0052	0.0071	0.0045	0.0011	0.0008	0.0204
[redacted]	0.0024	0.0062	0.0065	0.0051	0.0023	0.0039	0.0265
W[redacted]W	0.0024	0.0068	0.0079	0.0096	0.0058	0.0123	0.0448
NW	0.0022	0.0059	0.0080	0.0059	0.0024	0.0026	0.0271
N[redacted]W	0.0019	0.0049	0.0089	0.0062	0.0010	0.0004	0.0233
T[redacted]ALS	0.0231	0.0554	0.0781	0.0524	0.0151	0.0214	0.2454

W[illegible]NDROSE1_8789 run on 26-JUN-90 at 09:13:47 for RFP for the years 1987-89.
105216 records were read from the file.
[illegible]5847 records (81.6%) were included in the Joint Frequency Function matrices.
[illegible]9369 records (18.4%) had missing data and were excluded from the matrices.

STABILITY CLASS D

knts:	0.0-4.0	4.0-7.0	7.0-11.0	11.0-17.0	17.0-21.0	>=21.0	TOTALS
N	0.0005	0.0010	0.0010	0.0003	0.0000	0.0000	0.0028
[illegible]E	0.0017	0.0027	0.0030	0.0013	0.0002	0.0000	0.0090
NE	0.0016	0.0027	0.0028	0.0008	0.0001	0.0000	0.0080
[illegible]E	0.0015	0.0020	0.0021	0.0006	0.0000	0.0000	0.0062
[illegible]	0.0013	0.0016	0.0019	0.0003	0.0000	0.0000	0.0051
ESE	0.0009	0.0023	0.0022	0.0008	0.0000	0.0000	0.0062
[illegible]	0.0012	0.0030	0.0036	0.0015	0.0001	0.0000	0.0093
SSE	0.0017	0.0039	0.0051	0.0026	0.0003	0.0000	0.0136
[illegible]	0.0019	0.0040	0.0042	0.0017	0.0002	0.0000	0.0120
SSW	0.0022	0.0035	0.0036	0.0012	0.0001	0.0002	0.0109
[illegible]	0.0018	0.0036	0.0039	0.0016	0.0003	0.0001	0.0113
[illegible]SW	0.0022	0.0033	0.0043	0.0022	0.0007	0.0006	0.0133
W	0.0029	0.0048	0.0058	0.0045	0.0025	0.0032	0.0236
[illegible]W	0.0031	0.0050	0.0059	0.0079	0.0051	0.0082	0.0353
NW	0.0028	0.0055	0.0060	0.0053	0.0020	0.0029	0.0245
[illegible]W	0.0019	0.0038	0.0051	0.0028	0.0004	0.0002	0.0144
[illegible]TALS	0.0292	0.0527	0.0605	0.0355	0.0121	0.0156	0.2056

WINDROSE1_8789 run on 26-JUN-90 at 09:13:47 for RFP for the years 1987-89.
105216 records were read from the file.
85847 records (81.6%) were included in the Joint Frequency Function matrices.
19369 records (18.4%) had missing data and were excluded from the matrices.

STABILITY CLASS C

knts:	0.0-4.0	4.0-7.0	7.0-11.0	11.0-17.0	17.0-21.0	>=21.0	TOTALS
N	0.0003	0.0006	0.0006	0.0001	0.0000	0.0000	0.0015
NNE	0.0009	0.0016	0.0016	0.0003	0.0000	0.0000	0.0044
NE	0.0011	0.0020	0.0016	0.0004	0.0001	0.0000	0.0052
ENE	0.0009	0.0017	0.0013	0.0002	0.0000	0.0000	0.0042
E	0.0010	0.0015	0.0011	0.0003	0.0000	0.0000	0.0039
ESE	0.0010	0.0017	0.0017	0.0004	0.0000	0.0000	0.0049
SE	0.0011	0.0027	0.0025	0.0008	0.0000	0.0000	0.0072
SSE	0.0012	0.0028	0.0029	0.0012	0.0001	0.0000	0.0082
S	0.0011	0.0023	0.0019	0.0010	0.0000	0.0000	0.0064
SSW	0.0013	0.0020	0.0015	0.0006	0.0001	0.0001	0.0055
SW	0.0014	0.0020	0.0018	0.0006	0.0001	0.0000	0.0058
WSW	0.0012	0.0021	0.0019	0.0012	0.0003	0.0001	0.0068
W	0.0017	0.0029	0.0027	0.0025	0.0009	0.0007	0.0115
WNW	0.0017	0.0024	0.0029	0.0031	0.0014	0.0015	0.0132
NW	0.0020	0.0024	0.0029	0.0023	0.0010	0.0010	0.0116
NNW	0.0010	0.0014	0.0012	0.0010	0.0001	0.0002	0.0049
TOTALS	0.0188	0.0323	0.0301	0.0159	0.0042	0.0037	0.1051

WINDROSE1_8789 run on 26-JUN-90 at 09:13:47 for RFP for the years 1987-89.
105216 records were read from the file.
[illegible]5847 records (81.6%) were included in the Joint Frequency Function matrices.
[illegible]9369 records (18.4%) had missing data and were excluded from the matrices.

STABILITY CLASS B

knts:	0.0-4.0	4.0-7.0	7.0-11.0	11.0-17.0	17.0-21.0	>=21.0	TOTALS
N	0.0002	0.0003	0.0001	0.0000	0.0000	0.0000	0.0006
N[illegible]E	0.0004	0.0007	0.0004	0.0001	0.0000	0.0000	0.0015
NE	0.0008	0.0014	0.0009	0.0001	0.0000	0.0000	0.0031
[illegible]E	0.0008	0.0012	0.0008	0.0002	0.0000	0.0000	0.0030
[illegible]	0.0007	0.0009	0.0007	0.0001	0.0000	0.0000	0.0024
ESE	0.0006	0.0017	0.0010	0.0002	0.0000	0.0000	0.0036
S[illegible]	0.0007	0.0020	0.0016	0.0004	0.0000	0.0000	0.0047
SSE	0.0008	0.0018	0.0015	0.0005	0.0000	0.0000	0.0046
[illegible]	0.0008	0.0012	0.0010	0.0003	0.0000	0.0000	0.0034
SSW	0.0009	0.0013	0.0008	0.0004	0.0001	0.0000	0.0034
S[illegible]	0.0007	0.0011	0.0009	0.0004	0.0000	0.0000	0.0032
W[illegible]W	0.0008	0.0013	0.0010	0.0006	0.0001	0.0001	0.0039
[illegible]	0.0010	0.0014	0.0011	0.0010	0.0003	0.0001	0.0049
W[illegible]W	0.0011	0.0016	0.0014	0.0010	0.0005	0.0003	0.0059
NW	0.0010	0.0013	0.0012	0.0012	0.0003	0.0002	0.0051
N[illegible]W	0.0005	0.0006	0.0005	0.0002	0.0001	0.0001	0.0019
T[illegible]TALS	0.0117	0.0196	0.0149	0.0068	0.0015	0.0007	0.0552

WINDROSE1_8789 run on 26-JUN-90 at 09:13:47 for RFP for the years 1987-89.
105216 records were read from the file.
85847 records (81.6%) were included in the Joint Frequency Function matrices.
19369 records (18.4%) had missing data and were excluded from the matrices.

STABILITY CLASS A

knts:	0.0-4.0	4.0-7.0	7.0-11.0	11.0-17.0	17.0-21.0	>=21.0	TOTALS
N	0.0078	0.0127	0.0153	0.0104	0.0023	0.0009	0.0494
NNE	0.0036	0.0053	0.0041	0.0013	0.0002	0.0000	0.0145
NE	0.0022	0.0030	0.0015	0.0003	0.0000	0.0000	0.0071
ENE	0.0022	0.0027	0.0016	0.0003	0.0000	0.0000	0.0068
E	0.0025	0.0026	0.0014	0.0003	0.0000	0.0000	0.0068
ESE	0.0022	0.0030	0.0018	0.0002	0.0000	0.0000	0.0072
SE	0.0025	0.0040	0.0022	0.0005	0.0000	0.0000	0.0092
SSE	0.0020	0.0030	0.0020	0.0003	0.0000	0.0000	0.0074
S	0.0024	0.0025	0.0017	0.0005	0.0001	0.0000	0.0073
SSW	0.0026	0.0022	0.0017	0.0005	0.0001	0.0000	0.0071
SW	0.0024	0.0022	0.0015	0.0006	0.0002	0.0001	0.0069
WSW	0.0027	0.0025	0.0019	0.0007	0.0002	0.0000	0.0080
W	0.0025	0.0032	0.0019	0.0010	0.0002	0.0001	0.0089
WNW	0.0028	0.0030	0.0019	0.0013	0.0002	0.0001	0.0094
NW	0.0025	0.0027	0.0024	0.0011	0.0002	0.0001	0.0090
NNW	0.0045	0.0053	0.0048	0.0022	0.0005	0.0001	0.0175
TOTALS	0.0473	0.0599	0.0477	0.0215	0.0043	0.0017	0.1824

APPENDIX B

REVIEW OF PARTICLE SIZE AND PLUTONIUM RESUSPENSION STUDIES

1.0 ROCKY FLATS PARTICLE SIZE

A literature review on Rocky Flats respirable particle size studies as related to the deposition and retention of inhaled particles in the human respiratory tract was conducted. The review included investigation of:

a) factors affecting the deposition and retention of aerosols in the human respiratory tract;

b) aerosol behavior and dispersion as a function of physical and aerodynamic mean particle size; and

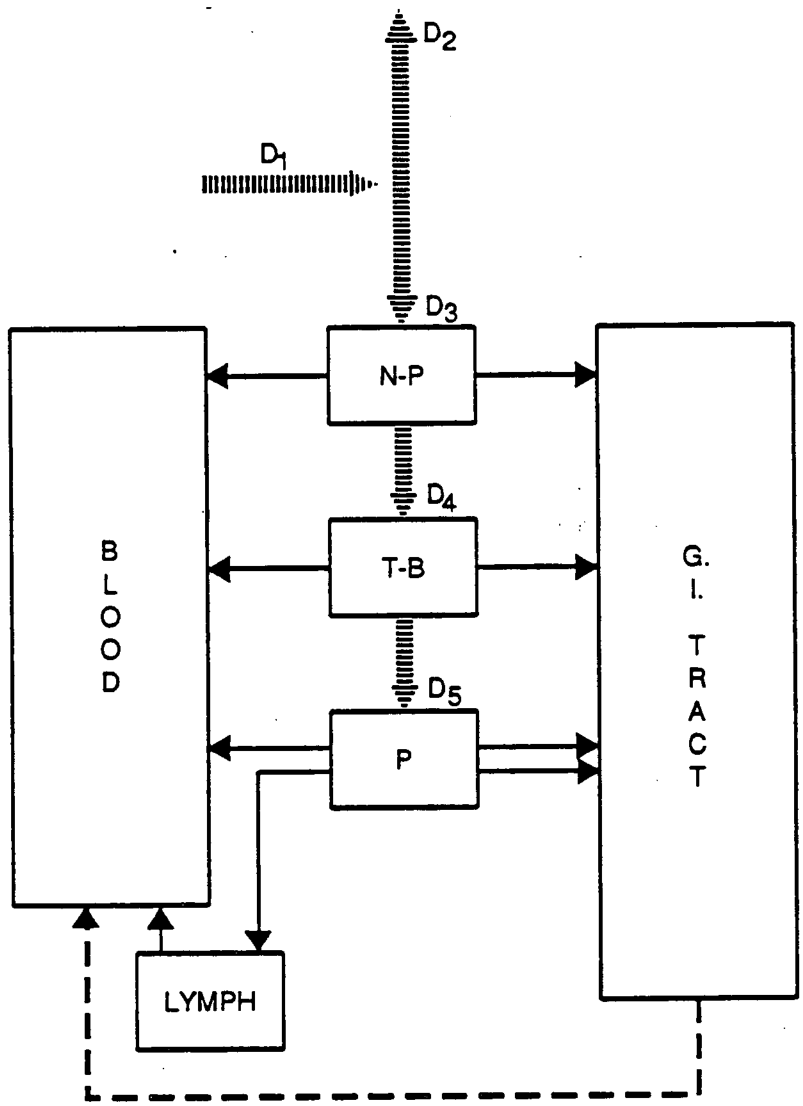
c) plutonium aerosol particle size studies that have been performed at the Rocky Flats Plant.

1.1 Factors Affecting the Deposition and Retention of Aerosols in the Human Respiratory Tract.

The International Commission on Radiological Protection (ICRP) Task Group on Lung Dynamics published the Human Respiratory model (ICRP 1972) in use today for human dosimetric evaluations for radionuclides. This model has been adopted by the EPA and DOE. The model divides the human respiratory tract into three compartments (see Figure B-1):

- **Nasopharynx (N-P):** The nasopharynx region begins with the anterior nares and extends backwards and downwards until the level of the larynx.

ICRP Lung Model (1971)



From: Inhalation Risks from Radioactive Contaminants IAEA Vienna 1973

Schematic Diagram Showing Clearance Pathways from the Various Deposition Sites

07/07/90 ICRP-LNG.DWG

Figure B-1

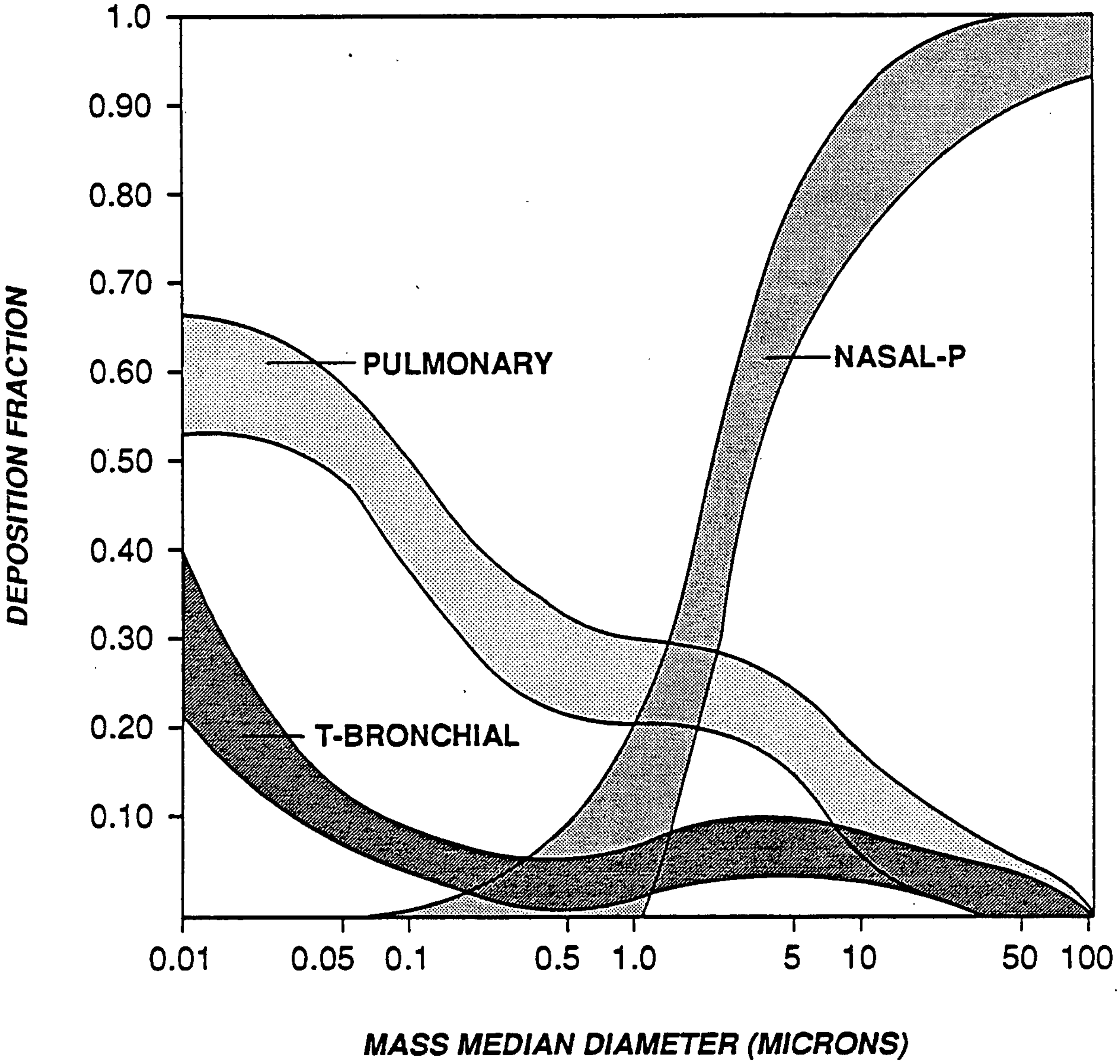
- **Tracheobronchial Tree (T-B):** The tracheobronchial tree consists of the trachea and bronchial tree down to, and including, the terminal bronchiolus.

- **Pulmonary Region (P):** The pulmonary region includes the respiratory bronchiole and alveoli.

Materials inhaled into the human respiratory track may have hold-up residence times in the pulmonary regions of days, weeks, or years depending on the solubility of the specific compound uptake. Uptake in the various regions will also vary as a function of particle size. Figure B-2 displays the disposition fraction as a function of the Mass Median Aerodynamic Diameter (MMAD) for each of the three respiratory tract regions of the lung model.

For the case of inhalation of plutonium particles, the model predicts rapid clearance, within 48 hours, of the total amount of material deposited within the N-P and T-B regions. It further postulates short-term clearance and elimination of 40 percent of the material deposited in the pulmonary region irrespective of particle size or compound class. The compound solubility class will determine, to some extent, the route of clearance; however, the remaining fraction within the pulmonary lung provides the major uptake to the systemic organ systems. In the case of RFP environmentally released plutonium, it is assumed to be insoluble Y class plutonium. However, Langer (1984) suggests that the Pu-239 may be more soluble than previously expected.

Many studies have been conducted to determine a practical particle size cutoff for particle deposition into the pulmonary region of the lung. While many studies indicate little or no deep pulmonary deposition for particles larger than 3 to 5 μm aerodynamic equivalent diameter (AED), the EPA and other regulatory



From: Inhalation Risks from Radioactive Contaminants IAEA Vienna 1973.

Figure B-2

agencies have settled on a more conservative approach and consider particles up to 10 μm AED to be "respirable" (EPA OWSER, 1989).

1.2 Aerosol Behavior and Dispersion as a Function of Physical and Aerodynamic Mean Particle Size.

1.2.1 Gravity Settling

Airborne particles are acted upon by gravity as a downward attractive force as they move about. This force is opposed by the buoyancy of the air and its resistance to the particle. These forces balance at equilibrium resulting in a settling velocity. This settling velocity is a function of a particle's size, density, and mass, as well as characteristics of the media (e.g., air) through which the particles move such as turbulence and viscosity.

1.2.2 Brownian Motion

Small particles are also subject to bombardment by gas molecules and other particles which causes random movement of the particles called Brownian motion. Brownian motion increases as particle size decreases, while the gravitational settling velocity decreases as particle size decreases. Brownian motion typically becomes a significant factor in comparison to gravitational settling velocity for particles of 10 micron (10 μm) or less. The effects of Brownian motion on small particles results in their being held aloft for a longer period of time and therefore in their being subjected to additional forces of wind turbulence.

1.2.3 Adhesion

Small particles, both solids and fluid droplets, are subject to violent Brownian motion. As these particles collide with each other and with other particles in the air they often adhere. As a result of this aggregation these larger particles tend to settle due to gravitational effects and they are removed from the aerosol. The rate of this removal process depends, among other things, on concentrations of the particulate particles, wind turbulence, particle shapes, and humidity.

1.2.4 Impaction

Inertial impaction occurs as particles in the air collide with and stick to obstructions. The strength of the impaction depends on the inertial speed of the particles and the angle of the surface with which impaction occurs. This is an important consideration for particle deposition in the upper respiratory system.

1.2.5 Aerosol Particle Size Distributions

Suspended particles in an aerosol are rarely spherical. The size of an irregularly shaped particle as measured will be larger than it's aerodynamic equivalent diameter. This aerodynamic equivalent diameter is the diameter of a unit density sphere having the same settling velocity as the particle in question of whatever shape and density. Direct measurement of the sizes of irregularly shaped particles, and measurement of spherical particles of similarity density having the same settling velocity, show that the diameter of the irregularly shaped particles is 1-1/3 to 1-2/3 times the diameter of the spheres having similar density.

In most situations, the aerosol particle size distribution curve will conform to a logarithmic normal distribution. Such a distribution is completely described by determining the geometric mean (M_g) and the geometric standard deviation (σ_g). This is done in practice by using logarithmic probability paper and plotting the cumulative percent less than the stated size against the size, resulting in a straight line.

The geometric mean, or median, is the size value where the straight line plot crosses the 50th percentile. The standard geometric deviation is similarly defined as follows:

$$\sigma_g = \frac{84.13\%\ \text{size}}{50\ \%\ \text{size}} = \frac{50\%\ \text{size}}{15.87\%\ \text{size}}$$

One method of determining a frequency distribution curve is by direct microscopic count of individual particle diameter and frequency of such particles. Another more common method is the distribution by mass using mass discriminating equipment. Because of the logarithmic probability law, if the distribution is obtained using either parameter, one can convert to the other as follows:

$$\text{Log } M_g = \log M'_g - 6.9078\ (\log \sigma_g)$$

where:

M_g = geometric mean obtained by microscopic count

M'_g = geometric mean obtained by weight

σ_g = geometric standard deviation obtained by weight or count.

This can be obtained by either the count median aerodynamic diameter (CMAD), or the mass median-aerodynamic diameter (MMAD).

The fractional deposition in each of the three respriatory compartments, as calculated by the lung model is sensitive to variations of the MMAD ranging from 0.01 to 100 μm. It is, however, rather insensitive to variation g from 1.2 to 4.5. The MMAD thus determines the fraction by weight of the inhaled particles which will be deposited in each lung model compartment within the above limits.

Using mass discriminating equipment and radioactive counting of the respectively separated sizes, the activity median aerodynamic diameter (AMAD) for an aerosol distribution can be determined. The AMAD provides an estimate of the fraction of inhaled air activity that is deposited in a particular lung model compartment.

1.3 RFP Plutonium Aerosol Particle Size Studies

Numerous studies of plutonium particle size distribution have been made of indoor work place air at RFP. Kirchner (1966) reported plutonium particle sizes in production areas of RFP ranging from 0.33 to 1.72 μm (MMAD) with an overall average of 0.88 MMAD and $_g$ of 2.02 based on autoradiographic studies of air filters. Studies of particles associated with glove failures and polyethylene bag leaks had mass median diameters of 4.1 and 1.2 μm, respectively. However, due to extensive HEPA filtration of workplace air, it is unlikely that this material has found its way to the environment.

It is inferred that the primary source of airborne Pu-239 in the RFP environment results from a plant release from an outside oil drum storage field, now known as the 903 Pad area. These drums contained Pu-contaminated cutting oil and carbon tetrachloride from machining operations. The oil had been filtered, resulting in suspended Pu particles of generally 3.0 microns in diameter or less (Rockwell, 1986). These drums were discovered leaking in 1959. Estimates place the total activity of Pu released from the drums in the 903 areas at 11 Curies (DOE, 1980). There have been numerous investigations performed over the years at RFP to attempt to determine plutonium particle sizes in the environment. Reported results of these studies have been rather variable and difficult to interpret. Early studies at RFP (Rockwell, 1986) involved soil surface direct autoradiography of 30 sod samples taken from the RFP buffer zone. The range of the Pu particles was reported as from 0.08 to 0.8 microns. The smaller Pu particles were attributed to stack effluent, whereas the larger ones were believed to originate from the 903 area.

Another similar study was performed on soil samples in 1976 (McDowell and Wicker, 1978). This study used soil from a biological study plot (0.75 hectares, 200 meters southeast of the 903 Pad) and involved microscopic examination and autoradiography. Autoradiographic results reported plutonium particles with equivalent diameters of 0.29 μm, 0.25μm, and 0.20μm for 7, 14, and 37 day exposures of soil to emulsion plates, respectively.

A one month study was performed by Sehmel (Sehmel, 1973) to investigate plutonium particle size and resuspension at RFP around the 903 Pad area. Sehmel used three sampling platforms and nearly 40 samplers set for specific wind ranges as well as continuous operation. Sehmel's results indicate 60 - 99 percent of plutonium particles to be in the respirable range based on the results of particle size measurements using cascade impactors.

Langer observes, however, (Langer, 1983, and 1989) that Sehmel in his work failed to coat the collection surfaces with adhesive to prevent particles from bouncing through the cascade impactor stages onto the backup filter. The coating of these surfaces is now a recognized, accepted procedure (Hering, 1989) to prevent particle bouncing through to the backup filter producing an incorrect bias toward a smaller particle size distribution.

Langer (1983, 1989) made extensive measurement of resuspended plutonium particulates over several years. In his work he utilized hi-vol samplers with selective particle size inlets of 15 μm AED, followed by 3-15 μm AED and $<3\mu$m AED cuts. Sampling was also performed at various heights (1, 3 and 10 meters above ground). Little correlation was found with height for the <3 μm AED and 3-15 μm AED cuts, due in part to the small amount of plutonium collected in these sample fractions. The larger particle size (> 15 μm) did show close correlation with height (activity decreased by a factor of 3 over a height of 1 to 10 meters). The amount of plutonium in the coarse (>15 μm) particle fraction was almost an order of magnitude higher than in the <3 μm fraction. It would appear from Langer's work that plutonium particles of $\leq$ 3 μm had attached to soil particles of similar or larger size. This finding is in contrast to plutonium particulate measurements from atmospheric fallout, where fallout, (Golchert and Sedlet, 1978) plutonium particles tended to attach to smaller particles rather than larger ones (due to the larger surface area to volume ratio). This difference is likely a result of initial plutonium aerosols generated by extremely high temperatures in the case of atmospheric fallout particles, as opposed to the filtered (<3 μm) particles from the 903 Pad area. In addition, the attachment process of Pu particles to soil particles is different from the attachment process of Pu particles to airborne dust particles.

2.0 SUMMARY OF RESUSPENSION STUDIES

2.1 Contamination Sources

As described earlier, the major source of fugitive plutonium-contaminated dust particles at RFP was drum leakage at the process areas in 903. Other lesser contributions include fires in 1957 and 1969, and very low level Pu releases from the plant. Releases through the plant's filtering system are reported to amount to approximately 15 μCi/yr. over the last 3 years for which data is available (Rockwell 1986b, 1987, 1988). In addition, worldwide fallout from nuclear weapons testing continues to be deposited. This factor has continually decreased over the past 10 years in the absence of atmospheric nuclear weapons testing.

2.2 Air Concentrations of Resuspended Plutonium

Compounding the problem of monitoring for plutonium in air is the phenomenon of resuspension. Resuspension is classically defined as the reentrainment in air of particulate materials which were previously in or deposited on the soil or other surrounding surfaces. Air concentrations of resuspended contamination (C) are often predicted by multiplying the ground surface contamination (G) by a resuspension factor k as follows:

$$C(Ci/m^3) = k(m^{-1})\ G(Ci/m^2), \text{ where:}$$

Ci = activity in Curies
m = meter

This allows an estimation of air concentration based on soil activity and various k factors depending on actual conditions to be made. Unfortunately, like many simple solutions, this approach has its limitations. K factors can vary greatly based on conditions of mechanical disturbance, soil moisture, silt and fines content of soil, wind, soil density, vegetative cover, and weathering. Weathering results when material deposited on surface soil migrates to the subsurface soil primarily due to repeated application of water (i.e., rain or snowmelt).

Over time a significant portion of the originally deposited material is removed from the surface soil and is no longer available for resuspension. Another aspect of the weathering effect is the tendency for small particles (<3 μm) to attach to the surface of larger particles which do not become airborne as easily. This tendency is influenced by the local soil chemistry and the chemical form of plutonium. Smaller surface particles which do not become attached become depleted in an undisturbed surface, further reducing the number of particles available for resuspension and lowering the airborne to soil ratio.

The phenomenon of resuspension of particulate plutonium has been studied in several environments. Probably the most studied location has been the Nevada Test Site (NTS). The majority of the plutonium contaminated sites at NTS resulted from atmospheric nuclear weapons tests. Significant residual plutonium remains in the immediate areas of these tests; however, because of the intense heat generated from the explosive event most of this plutonium is infused into a silica glass-like material and is simply not resuspendable without severe mechanical force. Resuspension factors (K) at these sites have been estimated to range from $10^{-12}m^{-1}$ to $10^{-14}m^{-1}$ for undisturbed site conditions.

There were, however, high explosive tests conducted at some NTS sites which were designed to have no nuclear yield, but which used plutonium components. These tests resulted in sites with high levels of plutonium contamination which is much less fixed. Resuspension at these locations under similar conditions ran 10^3 to 10^4 times higher (i.e., approximately $9 \times 10^{-9}m^{-1}$). The amount of vegetative cover found at the NTS is typically 5 to 15 percent, much less than that found at RFP. It should be kept in mind that these

Table B-1 Resuspension Parameters

Material	Depth of deposit z m	Resuspension Parameters: Resuspension factor, K m^{-1}	"Resuspension constant" Kz
Plutonium (Rocky Flats soil)	0.2	10^{-9}	(2×10^{-10})
	2×10^{-4}	10^{-6}	(2×10^{-10})
Plutonium (NTS soil)	~0.03	10^{-11}	(3×10^{-11})
Plutonium (mud flats)	0.001	4×10^{-8}	(4×10^{-11})
Plutonium (moist soil)	0.01	2×10^{-10}	(2×10^{-12})
Plutonium (SRP field)	0.05	10^{-9}	(5×10^{-11})
Uranium in soil			
(Surrey)	0.01	5×10^{-9}	(5×10^{-11})
(N.Y.)	0.01	1×10^{-8}	(1×10^{-10})
Radioiodine (from vegetation)		2×10^{-6}	

From: NUREG/CR-3332 Radiological Assessment

Resuspension levels of 10^{-11} to 10^{-12} are seen from Iranzo's (Iranzo, et al 1987) data for plutonium distribution on farm land following the Palomares nuclear weapons accident. Also noted in Iranzo's work is an increase in airborne levels at one sampling location caused by dirt work in a neighboring area without mitigation procedures being applied.

resuspension measurements for areas undisturbed by human activity are due exclusively to natural elements, principally wind.

Resuspension measurements for various DOE sites are summarized in Table B-1. At RFP, Langer (1989) has measured resuspension factors in the range of 10^{-13} to $10^{-10}m^{-1}$ in areas near the 903 pad. This range is for the pad in its weathered, undisturbed state. Sehmel (1972) made estimates of maximum resuspension factors at RFP in 1969 for plutonium releases during the pad remedial project. This project involved the use of earth moving machinery and occurred during a period when vegetative cover was minimal. Samples were taken over a period of six hours or greater in areas with resuspension factors ranging for 10^{-9} to $10^{-5}m^{-1}$.

2.3 Effects of Weathering

Studies have shown that weathering and migration of surface deposits deeper into the soil have significant effect on resuspension rates. Initial resuspension rates of 10^{-4} to $10^{-1}m^{-1}$ for fresh deposits tend to decrease with time even when migration is greatly inhibited (NRC, 1975). Sehmel (1976) found that material resuspended from an asphalt road by vehicle traffic was initially estimated at 10^{-5} to $10^{-2}m^{-1}$ per vehicle pass, but dropped 2 to 3 orders of magnitude within 30 days.

Several attempts to incorporate this weathering effect have been made. Linsley (1978) recommended a resuspension factor of

$$K(t \text{ in days}) = [10^{-6}\exp(-0.01t)+10^{-9}]m^{-1} \qquad \text{(eq. B-0)}$$

Linsley suggests that the 10^{-6} value is appropriate to well-vegetated soil but believes a higher value of 10^{-5} is more appropriate for desert environments. The Reactor Safety Study (NRC, 1975) used the following value:

$$K(t \text{ in years}) = [10^{-9}+10^{-5}\exp{-0.6769t}]m^{-1} \qquad \text{(eq. B-1)}$$

Part of the difficulty in arriving at an acceptable resuspension expression is the sparseness of data applicable to differing areas of climate, vegetation, and activity.

APPENDIX C

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